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EXTENDED EXPLORATORY DEVELOPMENT HOLOGRAPHIC HORIZONTAL DISPLAY

Final Report

November 1976

Prepared Under Contract N62269-76-C-0134

for

Naval Air Development Center

by

Automated Systems
RCA Government Systems DIV.
Burlington, Mass.
~~RCA~~

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This is a final report describing the effort conducted under Contract N62269-76-C-0134. The program addressed two specific areas concerned with improvement of the performance characteristics and configuration of the Holographic Horizontal Situation Display, HHSD, system under development by RCA to satisfy the HSD requirement of the AID cockpit concept. The areas of concern were:
(1) The definition and implementation of methods of improving the holographic recording process to allow the consistent production of holograms of ~over

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improved color fidelity and brightness; and

(2) the definition and implementation of methods of simplifying and improving the reliability of the retrieval system used to rapidly access and register the stored holograms.

FOREWORD

This report was prepared by the Electro-Optics Section of the Automated Systems Organization of RCA's Government Systems Division, under Navy Contract #N62269-76-C-0134. The effort was performed at RCA's Burlington, Massachusetts facility. The effort was sponsored by the Naval Air Systems Command under the sponsorship of Mr. George Tsaparas and technical direction of Mr. Russell Berthot. The program was administered by Mr. K. D. Quiring of the Naval Air Development Center.

The program was carried out under the direction of G. T. Burton, Manager, Design Engineering; B. R. Clay was the principal investigator. He was assisted by Messrs. R. F. Croce, D. A. Gore, E. C. Lea, R. E. Tetrev and Dr. R. A. Tuft.

HHSD DEVELOPMENT PROGRAM

OUTLINE

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATION (CONT.)

I. INTRODUCTION

This is a final report describing the effort conducted under Contract N62269-76-C-0134. The program addressed two specific areas concerned with improvement of the performance characteristics and configuration of the Holographic Horizontal Situation Display, HHSD, system under development by RCA to satisfy the HSD requirement of the AID cockpit concept. The areas of concern were:

(1) The definition and implementation of methods of improving the holographic recording process to allow the consistent production of holograms of improved color fidelity and brightness; and

(2) the definition and implementation of methods of simplifying and improving the reliability of the retrieval system used to rapidly access and register the stored holograms.

The contract also specified that RCA should, as called upon, provide consulting service to the Navy and the AIDS (previously AIMIS) system definition contractor to the extent required to fully explain the display concept, its advantages and limitations.

II. DEVELOPMENTAL HARDWARE

As a result of a series of Navy sponsored programs (See Appendix 1) and internal RCA programs, a Holographic Multicolor Information Storage and Display concept has been defined and tailored to meet the requirements of the Holographic Horizontal Situation Display requirement of the AIDS cockpit. Subsystems for holographically storing and displaying multicolor moving map information have been designed and implemented as laboratory feasibility and demonstration models. A facility for recording and duplicating the holographic storage tape strips used for the storage of multicolor data has been established and is maintained by

RCA in direct and dedicated support of the HHSD-AIDS program. A subsystem has also been defined for dynamic, alphanumeric and graphical annotation of the stored information. The characteristics and advantages of the multicolor storage concept have been defined and demonstrated. They are tabulated in Tables 2-1 and 2-2.

A. The Recording Subsystem

Consider first the nature of the recording system. The information storage mechanism used for the storage of multicolored data makes use of a focussed image hologram. The hologram is recorded in relief on photoresist coated on a mylar tape strip. Address and registration data, also recorded on the tape strip, is interrogated and used by a rapid retrieval system to control access to a designated portion of an addressed map segment. This data is also holographically recorded employing a holographic form that is highly redundant and as such has a high degree of immunity to scratches and abrasions.

The recording system of Figure 2-1 has been implemented and optimized for the recording of the holographic storage tapes. The system in its present configuration accepts as input source material, the elements of a color separation set formed at 1 to 1 as positive transparencies from an original printed map. The separations are imaged in a coherent system, one element at a time, to the recording plane. At the recording plane, superimposed interference patterns are formed between the image information and a reference beam for each element of the color separation set to form three registered holograms on the photoresist recording surface. Between recordings, the azimuth angle at which the reference beam strikes the reference plane is changed. Changing the angle forms the three interference patterns of different orientations of the fundamental grating of the hologram.

Broad band red, blue and green reference beams are used to readout the three stored focussed image gratings. Simultaneous readout of the three gratings allows the construction of three registered images of different colors to form a single full colored image. In addition to the recording of the multi-

TABLE 2-1

HHSD SYSTEM CHARACTERISTICS

I. DATA PRESENTATION FORMS

- MULTICOLOR MOVING MAP
- DYNAMIC MAP ANNOTATION

II. MAP DISPLAY (MULTICOLOR)

- IMAGE FEATURES

DISPLAY APERTURE:	5" DIAMETER VIEWING SCREEN (X18 GAIN)
RESOLUTION:	8 lp/mm, 40% RESPONSE
DISPLAY CONTRAST:	10,000 FT. CANDLES ENVIRONMENT
VIEWING DISTANCE:	30"
IMAGE PRESENTATION SIZE:	4/3 ORIGINAL MAPS SIZE
VIEWING EYE RELIEF AREA:	12" DIAMETER @ 30"
COLOR FIDELITY:	EQUIVALENT TO EXISTING AERIAL CHARTS
PROJECTION SOURCE:	WHITE LIGHT, 300 WATTS

- STORAGE HOLOGRAM

SIZE:	21mm x 21mm/FRAME
STORAGE DENSITY:	14.5" x 14.5" AERIAL CHART SEGMENT/FRAME
TYPE:	FOCUSSED IMAGE (PHASE)
MEDIUM:	PRESSED LEXAN
PACKING CONFIGURATION:	500 -21mm FRAMES ON A 45' - 35mm UNPERFORATED TAPE STRIP
ADDITIONAL DATA:	FRAME ADDRESS AND REGISTRATION INFORMATION

- TRANSPORT SYSTEM

TYPE:	REEL-TO-REEL, TWO MOTOR DRIVE FOR RAPID ACCESS, STEPPING MOTOR CAPSTAN DRIVE FOR FINE POSITIONING
ACCESS TUNE	
CONTINUITY JUMP:	600 ms TO JUMP FROM A GIVEN FRAME TO ANY OTHER FRAME WITHIN $\pm$ 30 FRAMES AND COME UP REGISTERED
LOOK AHEAD:	6 SEC (WORST CASE) ANY FRAME TO ANY OTHER FRAME
X-Y TRANSLATION:	TRACKING MODE TAPE POSITIONED TO 1/500 FRAME

TABLE 2-1 (CONTINUED)

III.	DYNAMIC MAP ANNOTATION-Direct View (Projected)	
	BRIGHTNESS:	VIEWABLE IN 10,000 FT. LAMBERTS ENVIRONMENT OVER MAP DATA, BINARY
	COLOR:	P-43, GREEN
	RESOLUTION:	COMPATIBLE WITH ALPHA-NUMERIC DATA PRESENTATION REQUIREMENT
	MEANS OF COMPOSITION:	STOKE

TABLE 2-2

HHSD SYSTEM ADVANTAGES

MAP DATA

- STORAGE MEDIUM
  - EASILY DUPLICATED
  - INEXPENSIVE
  - HIGH DENSITY
  - HIGH DURABILITY
- HIGH BRIGHTNESS (NON-ABSORPTIVE STORAGE MEDIUM)
- COMMON AREA MULTIPLE IMAGE STORAGE
- EASILY ANNOTATED

REGISTRATION AND ADDRESS DATA

- HIGH REDUNDANCY
- IMAGE IMMOBILITY

colored storage holograms, the recording table is implemented to allow recording of the address and registration data.

B. Display Hardware

The stored information is displayed using a projection optical system having the configuration shown in Figure 2-2. Paired, off-axis sources are used to interrogate the stored information.* As the readout beams pass through the storage medium, energy is diffracted down the optical axis of a projection lens system. The lens images the diffracted energy to a directional viewing screen. RCA has assembled a series of display models, employing the basic configuration of Figure 2-2, that demonstrate the high brightness and color fidelity of the holographic approach. Figure 2-3 is a system delivered to NADC under Contract N62269-71-C-0134. It was upgraded under Contract N62269-73-C-0609 and is currently in place in AIDS simulator at NADC.

The laboratory reader of Figure 2-4 has been used to evaluate the performance of the recording system and as a transportable demonstration unit. It was used continuously during this program to evaluate the quality of the recorded holograms.

The model of Figure 2-5 was assembled during this program. The characteristics of this system are discussed in more detail in Section III-B. This model is designed to house both the holographic multicolor map projection system and a projected CRT system for dynamic annotation of the map data. The dual optical paths of the two projection systems are shown in Figure 2-6. This program had as its objective, the implementation of a compact display, but was limited in scope to implementation of the multicolor display portion of the system only.

The model has incorporated within its structure, a high efficiency projection source (See Section III-B-1), a transport mechanism that was assembled

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*Two of six illumination sources are shown.

under Contract N62269-73-C-0609, but was reduced in size and its operation simplified under this effort (discussion of Section III-B-2), an image rotating prism, folding optics, and a 5" RCA-developed directional viewing screen.

Transport electronics also assembled under Contract N62269-73-C-0609, was modified under this program to accommodate the transport mechanism modification. The control electronics designed to control the transport mechanism when operated in rapid retrieval and tracking modes, may be, in its turn, controlled either by a switch register input or by a NOVA computer. NOVA compatible software that may be used to exercise the transport system is briefly summarized in Appendix II.

While the system of Figure 2-5 represents what RCA believes to be a minimum volume configuration for a dynamically annotated moving map display, an analysis of the performance of a dynamic annotation system employing a projection lens system to write alpha-numeric and graphical data over the map information is at best marginal in its performance capabilities. The use of a projection lens to relay the image from a 1.85" (or 2") diameter CRT presentation on to a 5" viewing screen, prevents the development of a display with adequate brightness to be used in the high ambient brightness of a cockpit environment. This conclusion is confirmed by the analysis following the lines of that presented in Section III-C. As a consequence, RCA has recommended that the Navy give consideration to the assembly of a direct view system having the configuration shown in Figure 2-7. This system is discussed in more detail in Section III-C.

C. Coating and Duplication Facility

RCA has established a coating facility within its laboratory to allow the coating of photoresist on a 35mm mylar tape strip (Figure 2-8). The photoresist-coated tape is the medium used as the original recording master. This system, and a deep understanding of the properties of the photoresist, developed through a painstaking and somewhat painful characterization program gives RCA the capability of producing recording material as required.

RCA is fully equipped to develop the exposed photoresist to produce original masters and to develop from these masters, metallic pressing masters. Stamping hardware (Figure 2-9) has been implemented, giving RCA the capability of producing duplicate lexan tape strips for use with the display system.

The material handling facilities just described above is more than adequate to handle storage tape production through a flight test program. Beyond an advanced development flight test system, more elaborate plating and pressing hardware will have to be developed to support the production of extended length tape strips in the volume required.

To complement the facilities described above, RCA now has in its laboratory, 16, 3-element color separation sets that cover a 600 (N-S) by 300 (E-W) nautical mile area of the Patuxent River vicinity. These separations were produced by the Navy (Naval Oceanographic Service) specifically in support of the Holographic Horizontal Situation Display program. As is the case with the coating and duplication facility, these separations are adequate to carry the program through an advanced development flight test phase.

III. PROGRAM EFFORT

A. The Recording Hardware

At the initiation of this program, there was in place, a recording system (Figure 2-1) that had been used to record both multicolor map information and edge track registration and address information. The system which at times produced holograms of excellent quality, could not be operated with the consistency required to produce extended length tape strips. Originally this inconsistency had been attributed to inconsistencies in the basic recording material - photoresist. Modification of the coating process and the introduction of more exacting controls during that process did improve the overall consistency of the recording process, eliminating the material consideration as a problem

and forcing the conclusion that the current inconsistencies could only be associated with problems of the recording table itself. Possible problem areas include:

(1) Variation in thermal gradients across the table

(2) Air turbulances within the shroud induced by either thermal air current, or external acoustic effects

(3) Table vibration coupled through mounts that did not meet the system original design criteria, and finally,

(4) Laser, the recording energy source, instabilities.

Another complicating problem that had to be faced and was addressed early in the program was that of simplifying the recording process so that an operator, when producing an extended length tape strip, would not make mistakes induced by inattentiveness resulting from boredom that required throwing away a tape strip and starting again. In addition, the complication of the procedure inhibited the investigation of the basic recording problems tabulated above.

It was decided to address this latter limitation first. A system was required that would simplify the recording process, or at least simplify the operator's participation in the recording process. A variety of approaches were considered, ranging from a review of step-by-step check-off list (the procedure currently used),to a highly automated system operating under computer control. This latter system would, if implemented, perform most of the steps of the recording process directing the operator to perform specific required functions that could not be easily implemented, by typing out instructions and waiting for either a sensor or keyboard-entered acknowledgement, before proceeding to the next step.

A middle of the road approach was taken, with the simple check-off list technique demonstrated to be inadequate and the full computer control approach felt to be too expensive to implement in both time and cost. The adopted approach made use of what, for lack of a better term, is called a "Control Serializer" approach.

The control console of this system is shown in the photograph of Figure 3-1. This system discussed in more detail in Appendix 3, is a hardwired logic system that inhibits an exposure operation unless the system has been properly cycled to place the system in the correct configuration to expose the corrected information based on a pre-defined sequence; namely, for the four map exposure case, the sequence of Appendix 3.

The system provides thumbwheel switch inputs for pre-setting exposure times of the 3 focussed image holograms, as well as for the address and registration holograms. Address sequences may be pre-set and generated automatically.

Exposure inhibit functions are set if the tape strip on which the recording is to be made is not in the correct position, if color separation is not of the correct address or color, if the numerous shutter and commutating mirrors of the system are not in the proper position, or if the table shrouds had been disturbed within the near past so that air turbulences in the table had not settled down.

This system, built and debugged during the early stages of this program, is now operational.

While the implementation of the serializer system increased the yield of the recording process, it still did not produce a system of sufficiently high reliability to allow the recording of the required extended length tape strips.

The symptoms of the problems that remained were typified by shading across the storage frame and color unbalance. The results were, as before, inconsistent. At times, holograms of excellent color fidelity could be produced, while at other times the results were poor. The inconsistencies were not correlated with photoresist coating lots - calibration gratings recorded on

another table showed the photoresist parameters to be consistent. The problem had to be associated with the table.

Early experiments - an interferometer was set up at various positions on the table - revealed a vibration problem associated with the suspension system. The table, during this period, was assembled in the laminated structure shown in Figure 3-2. The two top plates form a single element joined by metal blocks that lock the plates together by an epoxy bond. A foam material separates the two top plates and a base plate. The base plate is suspended over a plywood table top by an air cushion suspension system, implemented using four sectioned air mattresses and an inner tube. The plywood surface is supported by vertical 4" by 4" placed on six inch centers which sit above the floor on foam pads.

The air suspension system is a pressure regulation system. The table is leveled by adjusting the pressure in the 5 elements of the system and then during an exposure process, maintaining the pressure constant to maintain the table in its proper position and isolated from ground vibrations. The pressure in each segment of the system is maintained at the correct pressure by a low flow rate pressure regulator.

The system had two faults that were revealed by the vibration measurements referred to above. First, it did not provide adequate isolation from ground vibration, and second, the regulator action was not sufficiently smooth to prevent table motion introduced by the action of the regulator.

The first effect was felt to be in part due to compression of the foam damping material. (On smaller tables that were solely foam isolated, it had been our custom to replace the foam every six months.) The second was definitely demonstrated to be a problem with the regulator system.

A series of attempts were made to improve the characteristics of the suspension system. The foam was changed, offering some improvement, but of course, not solving the regulator problem. Vibration from the floor, though reduced, was still present. Better regulators were sought for our purpose and were not found. Attempts were made to disable the regulator system during the exposure operation, but drifts of the table over even that short a period, could not be tolerated. Pressure reservoir systems were evaluated and found too cumbersome to implement.

Consequently, when all short term cures were exhausted, it was obvious that a totally new suspension system was the only solution. Techniques used to effectively support a 3' x 8' table weighting 1000 to 1500 lbs could not be used for a 3' x 16' table carrying a weight in the order of 10,000 lbs.

Consultants were called in to review the problem. After performing a vibration survey of the floor, and considering the attenuation factors required to reduce table top vibration levels to levels that we are confident would allow consistent recording, a totally new pneumatic suspension system was recommended.

The proposed system is based on an optical table 16' long x 32" wide, with a total weight of 10,000 pounds, including all equipment on the table.

Barry*, the selected vendor, proposed to isolate the optical table on a Serva Levl vibration isolation system with 8 isolators. The arrangement is shown in Figure 3-3. A Serva Levl system with a vertical natural frequency of 0.7 Hz, and a horizontal natural frequency of 0.6 Hz, is proposed. The system will provide isolation as shown on the attached transmissibility curves (Figure 3-4). The system will function as a 3-point suspension system, even

* Barry, (Division of Barry Wright Corp.), 700 Pleasant Street, Watertown, Mass. 02172

with 8 isolators to prevent distortion of the optical bench. A pendulus horizontal stage is proposed which will produce horizontal natural frequency to 0.6 Hz. There are eight supporting structures, each having the configuration shown in Figure 3-5.

Initial consideration was given to implementing this sytem under this program. A review of the cost that would be incurred and the best installation schedule placed this consideration beyond the scope of the program.*

Further improvement in system stability could be achieved by adding to the table the stabilization system developed by RCA Zurich, and described in Appendix 4.

The remaining potential problem areas, namely: laser drift, thermal gradients, and acoustic noise problems were also evaluated. Variable thermal gradients and acoustic effects were quickly ruled out; the thermal effects by an extensive thermal couple survey, and the acoustic effects by measuring table top vibration during normal daytime operation and comparing these results with measurements taken late at night with all the in-plant machinery shut down. No significant reduction in the table top vibration attributed to air mass coupling could be defined, although some of the vibration components transmitted from the floor were eliminated.

Measurements made on the laser stability yield different results. The beam amplitude does vary on an hourly (sometimes faster) rate after stabilized operation is achieved; it normally takes several hours to reach stabilized operation. We have operated before in the presence of these variations and could

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* Subsequent to the completion of the program, a capital commitment was obtained to purchase the Barry Stabilization System. Installation should be complete by mid-December. With the completion of this installation and a final system alignment, RCA believes that the facilitation work on the recording and duplication hardware effort will be complete at least to the level required to support the HHSD program through flight test hardware.

do so in the future. However, the compensation is another operator function, a condition that could be avoided by the addition of an integrating exposure control system which would further reduce the probability of error during an extended recording cycle.

Reiterating, one of the stated objectives of the program was to improve the quality of the recordings. The modifications suggested above, while developed under the program, were not implemented - the funds were not available. Significant steps were taken, however, leading to the definition of system problems and establishing solutions to these problems. If the proposed solutions are implemented, it is our conviction that high brightness, high quality, holograms can be consistently recorded.

The current recording system produces holograms - paraphrasing the girl with the curl rhyme - that when they are good, are very, very good, but when they are bad, are horrid. The recording procedures and methods of setting the exposure parameters derived under Contract N62269-74-C-0331 when executed in a vibrationally stable environment, lead to bright - easily viewable in a 10,000 ft-lambert environment - holograms of excellent color fidelity.

The Barry solution to the stabilization problem is currently being implemented. A RCA capital commitment has been approved to purchase the stabilization hardware required to upgrade the holographic recording facility. At the time of this writing, an unsolicited proposal is in preparation for submission to NADC, that would use the upgraded system to produce extended length tapes for use with demonstration hardware.

B. Demonstration Hardware

The demonstration hardware of Figure 2-5, having the optical configuration of 2-6, was assembled under this program. The holographic projection system consists of the source assembly of Figure 3-6 and 3-7, the modified transport mechanism of Figure 3-8, a projection lens, an image rotating prism assembly folding optics, and a 5" diameter directional viewing screen. The assembly was

incorporated in a package having the outline dimension of Figure 3-9.

The source system is discussed in the next section.

The transport subsystem has been modified to accommodate the single-sided tape strip configuration. The performance of the transport system is described in a later section.

The imaging lens is a General Scientific, Series 102, 32mm - f/2 camera lens. It is inexpensive and can be readily obtained.

The image rotating prism is a Pechan prism; it will accept the diverging cone of the projection lens. Its acceptance aperture is 1.1 inch, more than adequate to accept the beam emerging from the imaging lens. The prism has a 80% transmission efficiency. It is housed in an enclosure that is 2.5 inches in diameter and 2.2 inches long.

The viewing screen is 5 inches in diameter. The screen construction is identical to that originally developed under Contract #N62269-70-0080 and described in the Final Report of that contract.

1. Source Assembly

The source assembly of Figure 3-6 is one that employs six tungsten halide bulbs. The bulbs are paired; two used for each of the three primary colors, as indicated in Figure 3-7. The colors are derived by broad band filtering the 3-paired sources to produce the red, blue and green readout beams. In an ideal system, the source would be a point; the reflector would be a perfect eliptical surface that would image the source point to an image point. For this idealized case, the readout plane is placed in the imaging cone so that only the active portion of the hologram - that portion of the hologram that is imaged to the viewing screen is filled.

In practice, the above condition is not the case. The source is a point and the eliptical surface is not perfect. The source geometry is optimized as shown in Figure 3-10. The readout area is generally over filled and the two axes of paired sources are oriented at slightly different angles to produce uniform illumination across the active hologram area. System efficiency is lost. This effect is particularly apparent with the source assembly of Figure 3-6 that uses the Sylvania ELR bulb. A broad survey of standard bulb assemblies had been conducted on previous contract and was updated on this program in an attempt to find a bulb assembly - source and reflectors - that could be used in the geometry of this program. None were found.

The absence of a good filament-reflector combination led to the development of the 6-element source assembly of Figure 3-11. The assembly with separate precision reflector and filaments, produced a display brightness that is 4 to 5 times that of the source assembly of Figure 3-6. It is, however, oversize. It is not compatible with the size constraints placed on the airborne package.

A scaled down version of precision source assembly of Figure 3-11 should be incorporated in future HHSD systems. Such a system, designed to the size constraints of Figure 3-9, would produce an increase in display brightness by a factor of 2 to 3 over the source assembly of Figure 3-7 used in the system assembled under this program.

This increased brightness results from an increase in system light collection efficiency and a reduction in the beam spread at the holographic storage plane. It allows the establishment of a tradeoff that allows either the reduction of source power below the 300 watts now required for 10,000 ft-lambert viewing, or the insertion of a beam combiner in the optical system of reduced efficiency to the holographic projection path and increased efficiency for the CRT display path.

The implementation of such a system would require the development of

new tooling and the selection of a different filament. The GE 1962 bulb is suited to the scaled down assembly. This is a 50 watt bulb.

2. The Retrieval System

The transport mechanism of Figure 3-12, designed for 16mm tape, was originally produced under contract #N62269-71-C-0134 and was delivered with the laboratory demonstration model of that program. A higher performance version, Figure 3-13, designed for a 35mm tape format, was later constructed in the configuration of Figure 3-14. This system, in its original configuration, employed a holographic storage format that required six holograms per frame - 3 focussed image holograms for storage of the multicolor information, two edge track holograms; one for the storage of X, the second for the storage of Y registration data, and a frame address hologram that was recorded in the image area but on the reverse side of the Lexan storage tape strip.

This method of information storage had a number of limitations:

(1) Readout of the address and registration information required three collimated beams derived from three GaAs diode sources, and three Reticon detection arrays. Incorporation of the readout system occupied considerable space in the transport mechanism layout.

(2) The frame address hologram was recorded in an area that was common to the map images. The efficiency of this grating had to be maintained at a low level to prevent crosstalk between the address and map information. The low efficiency requirement resulted in a reduction of the reliability of the frame address data on readout.

(3) Perhaps most significantly, the requirement to place the frame address hologram on the reverse side of the storage tape strip implied a double-sided registered duplication process; a factor that significantly complicated the duplication process.

To overcome these limitations, a single-sided tape configuration was devised and preliminary experiments performed during this program to confirm the merits of the revised system. In this configuration, the image information is recorded over a central 21mm x 21mm area, but the X-registration information is recorded in an edge track above the map storage frame, while Y-registration and frame address information is recorded in an edge track below the frame. The storage tape configuration and map arrangement is shown in Figure 3-15. This recording technique used for the recording of address and registration data is the hybrid Fresnel-Fraunhofer holographic approach previously described.[1] The X-registration hologram consists of the recording of a short line segment so that on playback, using a GaAs laser diode source, the line is imaged to a 512-element Reticon array with its long axis oriented so that it is orthogonal to the axis of the Reticon array. The line is recorded so that as the tape is moved in the X-direction, the line moves along the length of the array. The position of the line on the array is detected thus indicating the position of the hologram in the east-to-west direction within the film gate.

The Y-positional information assumes a different form. For this case, a series of bit positions are designated with the first position containing a double width pulse. This bit pattern, i.e., the pattern of Figure 3-16, is then detected to provide two pieces of information - namely: the position of the holographic tape strip within the view aperture and a bit pattern which indicates the frame number in the viewing aperture. As in the X-registration case, a 512 element array is employed. To allow full frame motion, the Y-determination is only used to indicate the Y-displacement with respect to the deck of the transport mechanism. Ideally, this should be a constant and should not require sensing. In practice, however, due to pressing tolerance and the force line through the tape strip as it is being transported, a positional variance of as much as $\pm$ 1mm

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[1] Final Report Contract #N62269-74-C-0331, May 1975

may be experienced or an amount equal to $\pm$ 1/20 of the frame height.

The Y-displacement error as measured from the tape deck is added to the output of a sensor that senses the location of the transport deck to create a control signal that indicates the position of the storage frame with respect to the optical axis of the projection system. The transport deck is moved to translate the storage frame in the N-S, or Y-direction relative to the optical axis of the projection system.

A recording system for production of the single-sided hologram was implemented on the recording table. During this program, X and Y address and registration holograms were produced, evaluated, and the recording system optimized in an iterative process, to produce holograms having the resolution and stability required for use with the Reticon readout system.

In parallel, the transport system of Figure 3-13 was modified to that portrayed in the sketch of Figure 3-17 and the photograph of Figure 3-8. In the region below the tape deck, the two implementations are basically the same, although the structure was modified to some degree to reduce the mounting depth required. The above deck sensor portion of the system was changed significantly, however. The old three-source, three-sensor configuration was removed and a more compact two-source, two-sensor system substituted.

The new system contains two laser sources with collimating optics that direct pencil readout beams through the X-registration, and the Y-registration and address holograms. Energy representative of the stored information is diffracted out of the reference beams by the storage holograms and directed to two 512-element Reticon readout arrays. The GaAs source diodes are pulsed at a 1 KHz rate to sample the film offset position in both X and Y and to determine the address of the storage frame in the viewing aperture. The interrogated information is decoded and used as a feedback signal in the servo control system used to position the tape strip. A simplified block diagram showing the elements of the servo system is presented in Figure 3-18.

The interface between the transport mechanism and the transport servo control electronics was modified during this program to accommodate the simplified readout system.

Retrieval operation was demonstrated using the modified system. Initial operation of the system demonstrated a 30 frame jump capability that exceeded the 600 ms design goal.* Limitation of the available source material prevented the demonstration of longer jump access times.** Attempts to operate the system in the tracking mode at low speeds resulted in an erratic response. The tape motion was not smooth, but rather progressed by variable size increments.

The dual mode operation - high speed retrieve, low speed tracking - of the transport system is produced by a changeover of the tape drive elements. During a high speed retrieval, i.e., a jump from a frame to any other frame having an address difference that is greater than three, storage tape motion is produced by unbalancing the torques produced by the two reel motors of Figure 3-17. When the detected address is within three of the desired frame address, the reel motor torques are brought in to balance so that the tape velocity is ramped down, stopping the tape with the desired frame in the aperture of the optical projection system, with about a 1/4 of a frame precision. When the frame is approximately positioned, the pinch roller shown in Figure 3-17 is engaged, transferring the control of the tape motion - position - to a capstan drive system. The capstan is driven by a stepping motor through a step down gear train to eliminate an error signal generated by comparing the sensed frame offset and the commanded offset.

During the X (East-West) positioning operation, the system is also positioned in the Y (North-South) direction. This positioning operation is

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*A system requirement is that the transport mechanism be capable of accessing a frame within $\pm$ 30 frames of the frame within the viewing aperture and come to designate registration position within that frame in under 600 ms.

**It is also a system requirement that access to any frame from any other frame on the tape strip be accomplished in under 6 seconds.

also performed by a stepping motor drive system that supplies a driving force to a three ball screw elevation system. Driving the ball screws raises and lowers the deck of the transport mechanism and consequently varies the position of the storage hologram relative to the optical axis of the projection lens to produce motion of the reconstructed image.

As indicated above, erratic motion was produced in both stepping motor drive systems. A major contributor to the erratic motion was traced to noise in the control electronics. Circuit modifications were introduced in a number of places to reduce the system susceptibility to noise. A particularly offending area was a comparitor circuit that was used in both the X and Y control channels. This circuit compared the sensed X and Y tape position, with the desired X and Y position (as designated either by a switch register or a computer input), to generate a digital error signal. The error signal was next converted to an analog signal before being amplified and used to control the action of the tape drive motors. These problems have been corrected and the electronic system now appears to be noise free.

This effort eliminated a major portion of the transport instability. There still appears to be a non-uniformity of image motion that can only be attributed to problems in the mechanism. At the termination of this program, these problems were under investigation but had not been solved.*

C. The Dynamic Annotation

As indicated above, the demonstration hardware of Figure 2-5 was laid out to allow the inclusion of rear projected CRT dynamic annotation system. A Dumont KC2977 tube having 1.85 inch diameter active area and a P-43 phosphor was selected and the design produced with this tube used as the typical bottle configuration. An outline drawing of the tube is shown in Figure 3-19. Its

* This problem is now being addressed under a current program.

characteristics are tabulated in the first column of Table 3-1.

Tropel was consulted in an attempt to define a lens configuration and the speed of the lens system that would fit within the package. A two section f/1.5, 6 inch lens with the included folding mirror was recommended as being realizable.

Having obtained the lens data, a photometric analysis was performed that showed limited performance of the dynamic annotation system at high ambients. The dynamic data to background contrast ratio drops to 2:1 at 2500 ft- lamberts. Consequently, RCA recommended - and recommends - that consideration be given to the implementation of the direct view system of Figure 2-7.* This system, employing two display apertures that are merged by a beam combiner, can be assembled in a package having the outline dimensions of 11.37"(H) x 7.25"(W) x 25.5"(L). The modified Dumont KC2980, Figure 3-20, has the characteristics listed in the second column of Table 3-1. For these conditions, the direct view system has the characteristics of Table 2-1. There is a tradeoff to be considered; the higher brightness direct-view system causes an increase in the size of the display package from 8½"H x 6-3/4"W x 25"L to 11.37"H x 7.25"W x 25.5"L. In making the tradeoff, consideration should also be given to the placement of the display in the cockpit. In the current AIDS configuration, the display is placed low down in the cockpit; as such, it probably does not see the 10,000 ft-Lambert environment, consequently, the realizable lower brightness might be acceptable.

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*The photometric calculations for both the projected and direct-view dynamic annotation systems are presented in Appendix 5.

TABLE 3-1

CATHODE-RAY TUBE CHARACTERISTICS

CHARACTERISTICS	KC2977	KC2980 (Modified)
Maximum Diameter	1.85"	5.75"
Active Diameter	1.45"	5.00"
Focus Method	Electrostatic	Electrostatic
Deflection Method	Magnetic	Magnetic
Deflection ∢	45°	45°
Tube Length (including Pins)	5.7"	9.31"
Line Width	6 mils @ CRT faceplate 20.7 mils @ 3.45:1 projection	11 mils @ CRT faceplate
Light Output	7,000 ft-l @ CRT faceplate 720 ft-l @ 3.45:1 projection*	2,000 ft-l @ CRT faceplate
Writing Speed	4,000"/sec @ CRT faceplate 13,800"/sec @ 3.45:1 projection	20,000"/sec @ CRT faceplate
Phosphor Type	P43 (high efficiency)	P43 (high efficiency)
Refresh Rate	60 Hz	60 Hz
Accelerator Voltage	12 KV	15 KV
Accelerator Current	$\leq$ 200 ua	$\leq$ 150 ua
Limiting Resolution (assuming Gaussian Spot Size)	6.5 line pairs/mm or 231 resolvable TV lines	4 line pairs/mm or 500 resolvable TV lines
Min Char size (@ 7 line/char)	145 mils @ 3.45:1 Projection	77 mils
Max # of 7 x 5 char/sec$^{(1)}$	28,000 char/sec	52,800 char/sec
Max # char/frame	303 char/frame$^{(2)}$	880 char/frame$^{(3)}$
Max length of Graphics	231" @ 3.45:1 projection	268"

* Assuming F/1.55

Note (1) $$\#\ \text{char/sec} = \frac{\text{Character Perimeter (inches)}}{\text{Character}} \times \frac{1}{\text{Writing Rate}}$$

$$\text{Eg: } \#\text{char/sec} = \frac{[7 + 7 + 5 + 5]\ 11 \text{ mils}}{1/20{,}000 \text{ inches/sec}} = 52{,}800$$

(2) Limited by Display Area and calculated for the case where there are no spacers between characters.

(3) Limited by maximum writing rate and considered for case where there are no spacers between characters.

IV. CONCLUSION AND RECOMMENDATIONS

The following accomplishments were achieved during the program:

1. A detailed analysis of the limitations of the recording system was performed. A number of system modifications were introduced to improve the system's performance. A new suspension system for the table was defined and has been subsequently ordered.

2. Control electronics was added to the recording system to reduce the complexity of the operator's involvement in the process. This addition has essentially eliminated operator errors that in the past had been the cause of faulty recording.

3. The transport mechanism, control electronics, and holographic format have been simplified to accomodate a single-sided storage format. At the same time, a reduction in the size of the transport was affected.

4. A new compact display configuration was designed that projected both the dynamic annotation and color map information to a common viewing screen. The holographic projection portion of this system was implemented.

It is recommended that in addition to the addition of stabilization system hardware, beam drift and laser intensity control servos be added to the recording table, as discussed in Appendix 1.

A facility for recording and duplicating holographic storage tape strips for use with the HHSD system has been established and is maintained by RCA in direct support of HHSD - AIDS program. Currently, the performance of this system is being upgraded with the addition of an improved stabilization system.

A direct-view storage system is recommended for the display of the dynamic annotation data. Superimposed and registered viewing of the multicolor map information and the dynamic annotation data in the recommended system would be accomplished by the use of a dichroic beam combiner.

The use of a direct-view dynamic annotation system will result in a display of higher contrast that can be achieved with the configuration assembled during this program. The direct-view system will be easily viewable in a 10,000 ft-lambert environment, current projection using the projected system limited system performance to approximately 2500 ft-lamberts. The cost of the improved performance is an increase in the display height of from 8.5 to 11.4 inches.

The implementation of a new, high precision source assembly is recommended, that employs a separate bulb and reflector configuration rather than the combined assembly currently in use.

RCA is fully equipped to produce the original holographic storage tape, to expose the multiple hologram storage frame, to develop the recorded tape, to produce holographic pressing masters, and to generate duplicate display tape for use with the display hardware.

Current hardware and existing color separation sets are adequate to support the program through an advanced development model flight test program.

APPENDIX 1

HOLOGRAPHIC HORIZONTAL SITUATION DISPLAY

Directly Related Navy Supported Programs

N62269-76-C-0390
HHSD Projection Display System Model

N62269-76-C-0134
Extended HSD Development

N62269-75-C-0186
Holographic Moving Map Continuation

N62269-74-C-0331
Holographic Horizontal Display System Development

N62269-73-C-0609
Holographic Horizontal Display System

N62269-72-C-0452
Holographic Multicolor Moving Map Display (System Definition)

N62269-71-C-0652
Holographic Multicolor Moving Map Display - Ground Support Equipment

N62269-71-C-0134
Holographic Multicolor Moving Map Display (Laboratory Model)

N62269-70-C-0080
Laser Holographic Multicolor Moving Map Display System

APPENDIX 2

TRANSPORT MECHANISM CONTROL SOFTWARE

The movement of the holographic maps is governed by digital signals generated by a NOVA computer, Model 1220. A block diagram of the system is shown in Figure A2-1. A software flow diagram is shown in Figure A2-2.

The NOVA 1220 computer had a 12K memory. The program for controlling the transport consists of approximately 1500 instructions and requires approximately 3K memory. The program is loaded using a high speed paper tape reader, and a teletype is used to provide initial start/stop, rate and directional instructions to the computer.

The computer outputs 8 bit parallel numbers for both vertical (Y) and horizontal (X) positions plus a 9 bit frame number. There are three commands for exercising the transport: (1) Position, (2) Slew and (3) Flight. POSITION will move the transport to a specific frame, X and Y position and hold that position until a new command is given. SLEW will move the transport to a frame, X and Y position, then proceed from that position at a given rate and a given direction until a limit is reached. FLIGHT is identical to SLEW except that instead when a given point is reached, a new rate and direction will be commanded.

Prior to utilizing one of the three commands, the computer must be loaded with X, Y and Frame number limits. This is done using the POINT routine. These limits are established for a given strip of holograms.

APPENDIX 3

STEPS INVOLVED IN THE RECORDING PROCESS

The recording of hologram tapes involves a number of steps that must take place in a given sequence. If, for any reason, the sequence is not followed exactly, the entire tape is rejected.

A means of monitoring the sequence of steps is therefore, necessary and has been set up on a control console backed by logic circuits. These circuits are fed by sensors which indicate the state of appropriate recording fixtures. Data processing of the sensed states and sequences leads the operator to the next step. In addition to state and prior history, it is also necessary to know the intensity level at the recording plane since this could drift beyond acceptable limits. An optical fiber bundle samples a control area near the center of the hologram image and samples both, the object for each primary, and the three reference beams. This information appears as digital values at the console. The state of alignment is also measured and indicated as a side-to-side intensity gradient. The gradient should remain near zero but might drift off during a long run. This is indicated by visual means.

The console indicates the following condition as alarms.

1. Vacuum Off
2. Vacuum sequence incorrect
3. Incorrect primary object in place.
4. Incorrect frame number
5. Gate state wrong
6. Incorrect primary reference beam
7. Incorrect shutter state
8. Field stops not set
9. Film transport in wrong position
10. X-Y hologram in wrong state
11. Y-hologram stepping cam does not correspond to entered binary number
12. Map hologram vs XY hologram commutator in wrong state

13. Translation sub-routine not correct

14. Air seal around curtains is broken

15. High voltage step not performed.

Some of alarms inputs derived from additional contacts on a console control switch and others are from micro switches used to sense such things as film gate position, etc. The vacuum sequence sense is derived directly from vacuum sensitivie switches used in the gate lines. The data processor must store the intended sequences and perform a correlation with actual steps as they proceed. The next proper step is indicated by lights so as to lead the operator.

Operation

The various steps are organized into subroutines as follows:

A. X-Y and address sequence (39 steps)

B. Translation sequence (12 steps)

C. Map exposure on Red, Green, Blue (28 steps) sequence

D. Mode sequence (assembly of the above subroutines so as to generate the appropriate number of frames for 1, 2, 4 or 32 maps on a single strip).

Steps in Sequence I are

Steps contained in A are:

1. Set frame number - This is done by setting the required frame number on the console switches and includes the number for leading or lagging frames which have X, Y and address holograms but no maps.

2. A console switch is used to configure the recording table for either map holograms (OBJ) or the X-Y holograms.

3. A console switch is used to operate a solenoid actuator for commutating the laser beam to the X or the Y recording path.

TABLE A3-1

X-Y ADD-SEQUENCE A

(39 Steps)

1. set frame number
2. set xy-obj sw to xy
3. set x-y sw to x
4. delay
5. set x exposure
6. send
7. set xy sw to y
8. reset cam
9. set y 1 ab exposure
10. send
11. advance cam
12. send
13. advance cam
14. set y2 exposure
15. send
16. advance cam
17. set y3 exposure
18. send
19. advance cam
20. set y4 exposure
21. send
22. advance cam
23. set y5 exposure
24. send
25. advance cam
26. set y6 exposure
27. send
28. advance cam
29. set y7 exposure
30. send
31. advance cam
32. set y8 exposure
33. send
34. advance cam
35. set y9 exposure
36. send
37. advance cam
38. set y10 exposure
39. send

4. A delay time appropriate to recording the X or Y holograms is now entered on the console.

5. The exposure for timing the X recording is now entered.

6. The command to expose is now sent if no alarms indications are present.

7. The actuator now places the laser beam in the Y path.

8. The Address Cam is reset to zero.

9. The Y-exposure is entered on the console.

10. The command is sent to expose the first in a sequence of Y bits.

11. The Cam is now made to advance in order to change the bit position of Y.

12. The command to expose is sent.

The previously determined bit assembly pattern is obtained by repetition of the above steps beginning with 9 and proceeding until all bits are exposed.

At completion of the above routine, the tape is now advanced in order to expose the next frame as described in Sequence B.

B. Translation Sequence (12 Steps) (Table A3-2)

1. Panel (a curtain on the recording) number 5 is removed to gain access to the film gate.
2. Vacuum switch #1 is turned on.
3. Vacuum Switch #2, 3 and 4 are turned off. This causes the film to be held only by the advance vacuum chuck and released by the others.
4. The film gate is opened to permit movement of the film.

TABLE A3-2

TRANSLATION-SEQUENCE B

(12 steps)

1. Curtain 5 down
2. Vac Sw 1 on
3. Vac Sw 234 off
4. Gate open
5. Pull Sw and move transport to near stop
6. Vac Sw 2 on
7. Vac Sw 3 on
8. Vac Sw 4 on
9. Gate closed
10. Vac Sw 1 and 3 off
11. Push Sw and move transport to far stop
12. Curtain 5 up

5. The advance actuator is now pulled until a stop is reached. This causes the film to be moved by a precise amount. Both the pulling operation and the completion of the stroke are sensed.

6, 7, 8 With new film now in position, the vacuum switches are operated in sequence causing successive vacuum chucks to pull down the film. The successive operations produce peristalic motion and imparts a truly flat conformity of the film to the exposure plane.

9. The film gate is then closed. This causes a pressure pad to push the film onto the reference surface.

10. The vacuum pad holding the film to the actuator is now released by Vac Swl and the vacuum pad directly over the center of the field of view, having already served its purpose, is released. If it were left on, stress lines in the film would affect the finished hologram. The film is now held by two vacuum chucks one on either side of the field of view.

11. The actuator is now returned to its initial position.

12. Panel 5 is now replaced to exclude air turbulence.

At the conclusion of the translation sequence, another X, Y and address hologram set is recorded by following Sequence A as described above. The translation sequence is again invoked followed by B, etc., until four XY address frames are exposed. At this point, the map hologram is recorded according to the procedure described in Sequence C.

Sequence C (Table A3-3)

The optical bench now undergoes a change from the Fresnel-Fraunhofer configuration used in the X and Y holograms, to the focussed image hologram paths. This is done by operating solenoid driven optical fixtures from the console control.

1. A switch marked XY-OBJ is turned to OBJ to accomplish the above indicated changes.

TABLE A3-3

RGB - SEQUENCE C

(28 steps)

1. xy-ob sw to obj.
2. curtain 3 down
3. place Red obj.
4. Corona
5. field stops up
6. curtain 3 up
7. ref com sw Red on
8. delay
9. set red exposure
10. send
11. curtain 3 down (fld st. down)
12. Grn object up
13. corona
14. field stop up
15. curtain 3 up
16. ref. com sw grn
17. delay
18. set grn exp.
19. send
20. curtain 3 down (fld. stops down)
21. blue obj. up
22. corona
23. field stops up
24. curtain 3 up
25. Ref com sw Blue
26. delay
27. set blue exposure
28. send

2. Panel 3 is removed to allow a map object to be placed in the object plane.

3. The red object is placed on its registration pins.

4. Since the object is a film, it tends undesirably to curl. However, it must be caused to lie in a plane. This is done by electrically charging it with a brief burst of corona. Electric attraction then causes the object to adhere to the plano surface of the object condenser lens.

5. The field stops are now rotated into position defining the hologram field of view. These stops define the edge with sufficient precision to allow image continuity in the X-direction. The left side field stop carries an array of microswitches for sensing the frame number and color of the placed object. If the wrong object is up, an alarm is given when the field stop is closed.

6. The panel is now replaced to prevent air turbulence.

7. That reference beam which provides the angles for red readout is selected by switching a shutter array.

8. A value for the delay between the closing of the panel and the initiation of exposure is now set into the console. This time interval is determined by noting cessation of turbulence inside the enclosed holographic table.

9. The exposure value for red is set into the console. It is based on the photometer indication and on photoresist sensitivity as well as red object base fog level.

10. A command to expose is now sent.

11-28. The panel (curtain) is again removed to change the object. The green object is placed on the pins and the same sequence of events is followed as from the placement of red above. Finally, the Blue object is placed and exposed following completing of the above sequence.

A complete listing of all steps in all sequences is shown below. Various modes are composed by altering the sequences as shown in Table A3-4.

TABLE A3-4

1 STRIP OF 4 MAP FRAMES
WITH 4 LEADING AND TWO LAGGING XYA's

1. A 1-37
2. B 1-12
3. A 1-37
4. B 1-12
5. A 1-37
6. B 1-12
7. A 1-37
8. B 1-12
9. A 1-37
10. C 1-27
11. B 1-12
12. A 1-37
13. C 1-27
14. B 1-12
15. A 1-37
16. C 1-27
17. B 1-12
18. A 1-37
19. C 1-27
20. B 1-12
21. A 1-37
22. B 1-12
23. A 1-37

370
108
128
606 steps total

APPENDIX 4

BEAM STABILIZATION SYSTEM

The discussion that follows has been extracted from an internal RCA report that describes an active stabilization system for holographic systems developed by M. T. Gale and H. Schiitz of RCA Zurich Laboratories. The system as described can be directly applied to the HHSD recording table.

1. Introduction

Optimum recording of a hologram requires that the interference fringe pattern remains stationary. Laser, thermal, air turbulences or table vibration are all factors that may cause fringe instability. A constant drift amounting to a relative phase change of 2π radians at the end of the exposure (i.e., a total fringe translation equal to the fringe periodicity at any point) will completely destroy the recording - the fringe pattern exposure integrates to a uniform exposure at every point on the recording area. Lesser or greater drifts give holograms with less than optimum reconstruction efficiencies and, *in particular, the existence* of random drifts and oscillations results in a series of holograms recorded under otherwise identical conditions having varying reconstruction efficiencies.

The stabilization technique described in this report was developed in conjunction with work on the recording of color-encoded focussed image holograms. Each of these holograms is a superposition of three component holograms recorded from the red, green and blue image components. Any variation in the efficiency of one of these component holograms leads to a change in the color balance of the final reconstruction - a 5% intensity change in one of the primaries, for example, gives a readily observable color shift.

The standard techniques for minimizing the instabilities in holographic recording systems are all passive ones. Ideally a stable, vibration-damped

holographic table is used in an air-conditioned, temperature stabilized room and an enclosure is built around the optical system to minimize air movement in the light paths. The feasibility and degree of success of such precaustions depends upon the instabilities present in the environment, the exposure times and the characteristics of the individual recording system. Problems are most likely to be encountered in a system using long path lengths and when exposure times in the order of seconds or longer are required as is usually the case when recording in non-silver media such as photoresists and photopolymers.

This report describes a supplemental approach to the holographic stability problem - the <u>active</u> stabilization of the interference fringe pattern by sensing the relative phase of the interfering wavefronts and holding it constant during the exposure by varying the path length of one of the beams as required. In practice, this is sufficient to give excellent stabilization, since the dominant phase variations can be expressed in terms of pure path length changes in the beams, and angular changes in beam direction are normally insignificant.

2. Origins of Instabilities

We consider here the origin and order of magnitude of the instabilities present in typical holographic recording systems. Three main types of instability may be distinguished - vibrations, thermal effects and air density fluctuations. The first two act on the various optical components and mounts in the system to introduce changes in the path lengths of the individual beams and thus in phases of the interfering wavefronts at the hologram recording plane; fluctuations in air density give refractive index changes which directly affect the beam phases.

(a) Vibrations - Vibrations are present to some degree in most environments, particularly as impulses which set the holographic table oscillating in a number of modes. Modern holographic tables are designed to minimize this

effect and to provide good mechanical isolation of the table surface from the floor. The isolation is excellent at high frequencies but becomes progressively worse towards lower frequencies, becoming ineffective in the region 1-2 Hz. Figure A4-1 shows the characteristics of a typical commercial table with a resonance frequency of about 1.6 Hz - the isolation and damping is very good at frequencies greater than about 5 Hz and the main response to an impulse excitation is a low frequency ringing at the 1.6 Hz resonance which will be seen as a decaying oscillation in the relative beam phases in the recording system.

(b) Thermal Effects - Small temperature fluctuations and drifts will result in expansion and contraction of the metal and glass components forming a typical holographic system and also of the table itself.

(c) Air Density Fluctuations - Pressure and temperature fluctuations in the air result in refractive index changes which affect the beam phases. These effects are most severe in systems using long path lengths and well separated beam paths. For a typical air conditioned room observed time constants for such fluctuations are in the order of 0.5 to 1 second. Effects are minimized by careful shielding of the optical system from strong air currents, although this conflicts with the requirement for good temperature stability.

3. Active Stabilization

The active stabilization scheme will be described in terms of a focussed image hologram recording system since this is the simplest and also one of the most suitable applications. Figure A4-2 shows a typical recording system. The laser beam is split into two parts - the reference beam A and the object beam B which forms an image of the two-dimensional transparency at the recording plane. The interference of beams A and B at the recording plane gives the intensity fringe pattern which forms the hologram. In this simple case the fringe pattern is a grating - like, sinusoidal intensity pattern which is amplitude modulated by the object information. Figure A4-2 also illustrates the translation of the fringe pattern resulting from a change in the relative phase of beams

A and B due to instabilities such as those described in the previous section. It is assumed here that the dominant effect of such instabilities can be expressed in terms of a pure change in the effective (i.e., optical) path lengths of the beams and that sideways or angular displacements are insignificant. The fringe pattern is relatively insensitive to the latter effects. Mirror M1 is shown as mounted on a piezoelectric crystal movement such that it can be moved in the direction shown by small amounts ($<$ 1 um) to vary the path length of beam B (the associated sideways movement of the beam is insignificant). The effect of such a movement is thus to change the relative phase of beams A and B at the recording plane and to translate the fringe pattern. Conversely any translation of the fringe pattern due to instabilities in the recording system can be corrected by a compensating motion of the mirror M1. Thus stabilization of the fringe pattern can be achieved by sensing the relative phase of beams A and B and holding this constant by appropriate movement of mirror M1.

The relative phase of the two interfering wavefronts is monitored using a simple holographic interferometer. This consists of a pre-recorded hologram positioned close to the recording area. The hologram is recorded from beams A and B on a substrate mounted such that, after development, it can be accurately replaced in its former position. The hologram should be efficient and is best recorded in photoresist (e.g., Shipley AZ1350). Figure A4-3a shows the reconstructed wavefronts on replacing the recorded hologram and illuminating again with the two beams. A mask is used to block all off-axis beams, leaving only B_o (the zero order from B) and A_{-1} (the -1 diffracted order from A). These two wavefronts are identical and can intefere constructively or destructively depending on the relative phase of A and B. Thus monitoring the intensity of the combined wavefront using a small photocell enables changes in this relative phase to be measured. A it changes the signal intensity goes through maxima and minima as shown in Figure A4-3b. The intensity at the photocell is given by

$$I_p = a^2 + b^2 + 2ab\cos\theta \qquad (1)$$

where a, b, are the amplitude of A_{-1} and B_o

θ is the phase difference of A_{-1} and B_o (or A and B)

For a linear photocell characteristic, the photocell signal across the load resistor, V_p, thus varies with θ according to the relation

$$V_p \propto a^2 + b^2 + 2ab\cos\theta \qquad (2)$$

In practice it is best to work with $a \sim b$ to keep the dc signal component small compared to the minimum to maximum amplitude - the ratio a:b can be adjusted by varying the hologram efficiency and by placing a suitable filter in beam B.

If the hologram H1 is not accurately repositioned the wavefronts B_o and A_{-1} are not parallel and coarse interference fringes appear in the combined wavefront; however providing the resulting fringe spacing is considerably greater than the photocell dimension this effect is not important. In practice this requirement is readily achieved by proper design of the hologram mounting.

The photocell signal, V_p, can now be used to derive a correction signal for stabilization. An effective technique is to use the slope of the V_p versus θ curve to derive a correction signal for stabilization - this slope can be measured by applying a small phase modulation ($\ll 2\pi$) to one of the beams and measuring the resulting photocell signal.

This technique is illustrated in Figure A4-4. A periodic voltage (frequency f_o) is applied to the piezoelectric crystal, giving a small, constant modulation in the phase of beam B. The detailed voltage waveform and frequency is not critical, but the frequency should be well above the maximum frequency at which the stabilization should function (also, maximum crystal response is obtained at a crystal resonance frequency). An oscillator giving a 5 kHz square wave output has been found to be suitable in most cases. The voltage amplitude is set such that the mirror M1 oscillates with a constant amplitude which is small compred to that required to give unit fringe shift in the interference

pattern - about 1% of the unit fringe.

The incorporation of this stabilization scheme in a focussed image hologram recording system in use at the Zurich Laboratories was found to give considerable improvement over the non-stabilized system. Using a 100 msec integration time constant at the output of a phase detector used to detect the error signal, the stabilization system functioned satisfactorily up to frequencies in excess of the holographic table resonance frequency of about 2 Hz. The effects of thermal drift and air movement were completely eliminated and those of floor vibrations considerably reduced. A severe floor tremor or table impact sets the table oscillating for many cycles of the mechanical resonant frequency; with stabilization this motion was compensated completely after the first half cycle. The spread in the diffraction efficiencies of a series of identically recorded holograms was minimized and showed considerable improvement over the non-stabilized series.

4. Conclusions

The degree of improvement resulting from the use of active stabilization depends upon the individual application and the magnitude of the instabilities present in the holographic recording system. For applications such as those quoted in the introduction and typified by holograms recorded from 2-dimensional objects or point sources, it enables the ultimate in hologram reproducibility and accurate fringe profiles to be achieved. In very unstable invironments, with large temperature fluctuations or air movements for example, it can provide sufficient stability to enable holograms to be recorded where this was previously not possible. Between these two extremes there exists a range of applications for which active stabilization gives improved holograms, reduced exposure times, and a relaxation of the passive stabilization precautions required.

APPENDIX 5

DISPLAY BRIGHTNESS ANALYSIS

PROJECTED CRT SYSTEM

General

In analyzing the display brightness, there are two aspects to be considered: the holographic projection system, and the dynamic data presentation. Consider first the holographic projection system.

Holographic System

For the systems of Figures 2-6 and 2-7, the holographic projection paths are, from a photometric viewpoint, similar. The single difference between the two systems is the location of the beam combiner in the optical path. For the system of Figure 2-6, the projected CRT system, the beam combiner is substituted for a folding mirror in the projection path between the holographic projection lens and the viewing screen. In the direct-view system, the beam combiner is placed in front of the viewing screen with the result that an additional reflecting surface is introduced in the optical path.

The elements of holographic projection system are tabulated along with experimentally derived efficiencies, in Table A5-1. The result is a system having an overall apparent optical efficiency of .068 for the system with one mirror and 0.58 when two mirrors are in the optical path. The six lamps of the source assembly, when operated at 300 watts, produce 16 lumens/watt (a color temperature of $2800^{\circ}K$) resulting in a total radiated flux density of 4800 lumens before filter (the source collection efficiency factor includes the filter losses). The resulting apparent luminosity of the viewing screen is then:

$$\frac{\text{optical efficiency x radiated flux}}{\text{screen area}}$$

or 2200 ft-Lamberts for one mirror or 2000 ft-Lamberts for two mirrors.

TABLE A5-1

HOLOGRAPHIC PROJECTION SYSTEM

BRIGHTNESS CALCULATION

OPTICAL EFFICIENCIES	
Source Collection	0.05
Holographic	0.10
Pechan Prism	0.80
Mirror(s)	0.92 (0.85)
Viewing Screen (X Gain)	20
Beam Combiner	0.85
Combined	.063 (.058)

Source Conversion Efficiency ($2800^{o}K$)	16 lumens/watt
Screen Area (5" diameter)	0.136 sq. ft.
Source Power	300 watts

$$\text{Effective Screen Luminance} = \frac{\text{Optical Efficiency x Source Efficiency X Source Power}}{\text{Screen Area}}$$

$$= \frac{16 \text{ x } 300 \text{ x } .063}{0.136}$$

$$= 2200 \text{ lumens/sq. ft } (2000 \text{ lumens/sq ft})$$

Assuming a 4:1 contrast (defined as $\frac{I_{max} - I_{min}}{I_{min}}$) is required for ease of viewing at high cockpit brightness. I_{min} must be less than 440 ft-Lamberts or 1/5 the highlight luminance. Assuming a screen reflectivity of 3.5%, a reasonable value for the V-coated sandwich of the directional viewing screen of Figure A5-1 a 12,500 ft-candle ambient brightness is implied, a value that is above the maximum 10,000 ft-candle brightness.

Let us go back and consider the efficiencies of the various elements of the holographic projection system.

Source Assembly

A high apparent screen brightness could be obtained by modifying the characteristics of the viewing screen to reduce the eye relief area. To a first approximation, the apparent screen brightness increases inversely as the square of the diameter of the eye relief area.

Source Efficiency

The source assembly consists of six bulbs in the configuration of Figure 3-11. Associated with each bulb is a broad bandpass filter that limits the radiated energy to a bandwidth equivalent to 1/3 of the optical spectrum. The bulbs are filtered such that there are two red, two blue and two green sources. The effect on source efficiency is to immediately reduce the efficiency to 33%.

Parabolic reflectors of high efficiency collect energy over a sold angle of 220° from each bulb. The bulb, and filament, however, act as a central blockage and the inability to concentrate all of the energy within the 5mm active area of the hologram creates a collection source having an effective f-number of 1.2. As a consequence, the collection efficiency from a single bulb is 0.15 before, 0.05 after filtering.

Holographic Efficiency

The focussed image hologram is recorded as a phase hologram. A phase hologram has a maximum efficiency of 33%. When used in a multicolor system, it is required to reduce the hologram efficiency to prevent intermodulation between the holograms of different colors. Optimum recording, striking a balance between intermodulation and efficiency, results in a 0.10 peak white holographic efficiency.

Projection Lens

The projection lens has a limited number of elements and can easily be designed with a transmission of 0.88.

Pechan Prism

The Pechan prism is included in the optical path to allow rotation of the image on the viewing screen. When properly coated, this prism has a transmission efficiency for white light of 0.80.

Folding Mirrors

There are 1, 2 or 3 folding mirrors, depending on the selected configuration, in the optical path, each with a reflection efficiency of 0.92.

Viewing Screen

The viewing screen is a unique device in the sandwich configuration of A5.1. It has a transmission efficiency of 0.965, reflecting only 3.5% of the energy.

The system consists of a condenser lens and specially designed lenticular screen.

The result is to concentrate the energy passing through the viewing screen to an eye relief area 12 inches in diameter at 30 inches. The screen has an effective gain of 26. When modified for a distribution of energy that cause energy to fall outside the active eye relief area, the true screen gain is of the order of 22 producing an effective screen gain efficiency when coupled with the transmission loss, of approximately 20.

Dichroic Beam Combiner

Both holographic systems employ a beam combiner that transmits the green of a P-43 phosphor while reflecting the remainder of the visible spectrum. A beam combiner has been obtained that reflects 85% of the energy outside the 200 Å green band of the P-43 phosphor, while transmitting 88% of the green information.

Dynamic Annotation Subsystem Brightness

As previously indicated, the dynamic annotation system may be implemented in either the projected configuration of Figure 2-6 or the direct view configuration of Figure 2-7. The Dumont KC2977 and a modified version of the KC2980 may be used for the former and latter implementations. If operated with a high efficiency P-43 phosphor, these tubes have the operating characteristics previously presented in Table 3-1 (pg. 22).

Projected System

Consider first the projected display system. A 2.0-inch (1.85" active diameter) CRT was selected for this implementation after a tradeoff study was conducted to determine the best match between the CRT size, lens size and placement, and the overall dimensional constraints imposed by the package.

Discussions with Tropel indicated that a split lens system, i.e., there are two element groups on either side of a folding mirror, Figure A5-2, could be constructed having a 6" focal length and an f/1.5 speed that would match the system's dimensional requirements. With this lens assuming the KC2977 performance - a brightness of 7000 ft-Lamberts at a writing speed of 4000 inches per second[1] - the luminous flux density on the viewing screen becomes 44.5 lumens/sq. ft.[2]

---

(1) The system is assumed to operate in the stroke mode, i.e., the continuous tone raster presentation mode of operation is not practical.

(2) $$L = \frac{\beta t}{4(F)^2 (1+m)^2} = 44.5$$

L = lumens/sq. ft. incident on the viewing screen
β = source brightness, 7000 ft-Lamberts
F = projection lens f/#, 1.5
M = magnification, 2.7
t = lens transmission, 0.90

For the directional viewing screen the energy passing through the screen is collected by a collection lens and directed toward a circular (12 inch for a point object) eye relief area at a distance of 30 inches. The action of this screen when used with the CRT system is to spread the projected CRT energy over a circular area that is approximately equal to the exit aperture of the projection lens plus the eye relief dimension as determined by the dispersive element of screen. For the geometry of this system, the CRT eye relief area is of the order of 17 inches.

The gain of the viewing screen, assuming that the energy density across the eye relief varies as the $\cos^2$, is:

$$G = \left[\frac{r^2}{r^2 + d^2}\right]^{-1} = 4.2$$

r = radius of eye relief area, 17"

d = viewing distance, 30"

Consequently, the effective screen brightness is equal to screen gain times the screen brightness as defined above or 182 ft-Lamberts.

Assuming only the CRT data is to be viewed and that 2:1 is an acceptable viewing contrast, then the background brightness level allowable is 91 ft-Lamberts. Further assuming that the viewing screen is the only reflective element in the system and has a 3.5 reflectivity, a fact confirmed by experiment, then the ambient brightness cannot exceed 2600 ft-Lamberts.

Further, if it is required to overwrite the annotation data over the map information, as it is, a beam combiner is required. Assuming a beam combiner peaked for the green spectrum of the P-43 phosphor that has an 80% transmission over the green band P-43 band then the system is only capable of producing acceptably bright image in an ambient that is limited to below 2500 ft-candles, a value that is 4:1 below the 10,000 ft-candle environment of the cockpit.

Direct View System

An analysis of the type described above led to the consideration of a direct view system having the configuration shown in Figure 2-7. For this system, a modified version of Dumont's KC2930 may be employed. This tube operated at a writing rate of 20,000 inches per second, has a display brightness of 2000 ft-Lamberts from a P-43 phosphor when operated at 15 Kv acceleration voltage with a 150 uA beam current.

A high brightness alternative is to employ a Westinghouse gun structure with a P-43 phosphor. Over a 5" x 5" raster, this tube will produce a 2000 ft-Lambert luminance with an acceleration voltage of 20 Kv and a 600 uA beam current. The spot size under these operating conditions is .008" as measured by the shrinking raster technique. A drawback is a limited life resulting from cathode failure at the high beam currents. The MTBF with a 20% duty factor is 500 hours. This is interpreted to mean that for a normal video presentation where peak brightness is only achieved a fraction of the time, the tube should meet the 500 hour MTBF criteria. Assuming primary alpha numeric and graphical presentation with a 20% duty factor, the MTBF should be 500 hours. For systems of reduced display density, the MTBF should increase. For highly saturated radar presentation, the MTBF will decrease. For the purposes of the discussion, the tube is said to have failed when the tube output power has dropped to 1/2 its original value.

A second disadvantage of the latter system is that as a consequence of the 20 Kv acceleration voltage, the tube must be shielded for soft X-ray radiation. This implies the use of a lead glass filter in front of the tube which will cause an attenuation of tube brightness.

However, in either case - the stroke or raster mode-operation, it is assumed that the 2000 ft-Lambert screen brightness can be achieved and that a dichroic filter on a lead glass substrate can be fabricated having a transmission efficiency of 85%. With the narrow band green filter, it is assumed that without a polarizer, 3% of the received ambient energy will be reflected from the viewing aperture. For this case, as in the case of the multicolor information, if a

4:1 contrast is required $\left[\text{contrast is defined as } \left(\frac{I_{max} - I_{min}}{I_{min}}\right).\right]$ For the 2000 ft-Lambert CRT, the apparent screen brightness after filtering, is 0.85 x 2000 or 1700 ft-Lamberts. At a background luminance level 1/5 that value or 340 ft-Lamberts, an allowable ambient brightness of 11300 ft-Lamberts is implied.

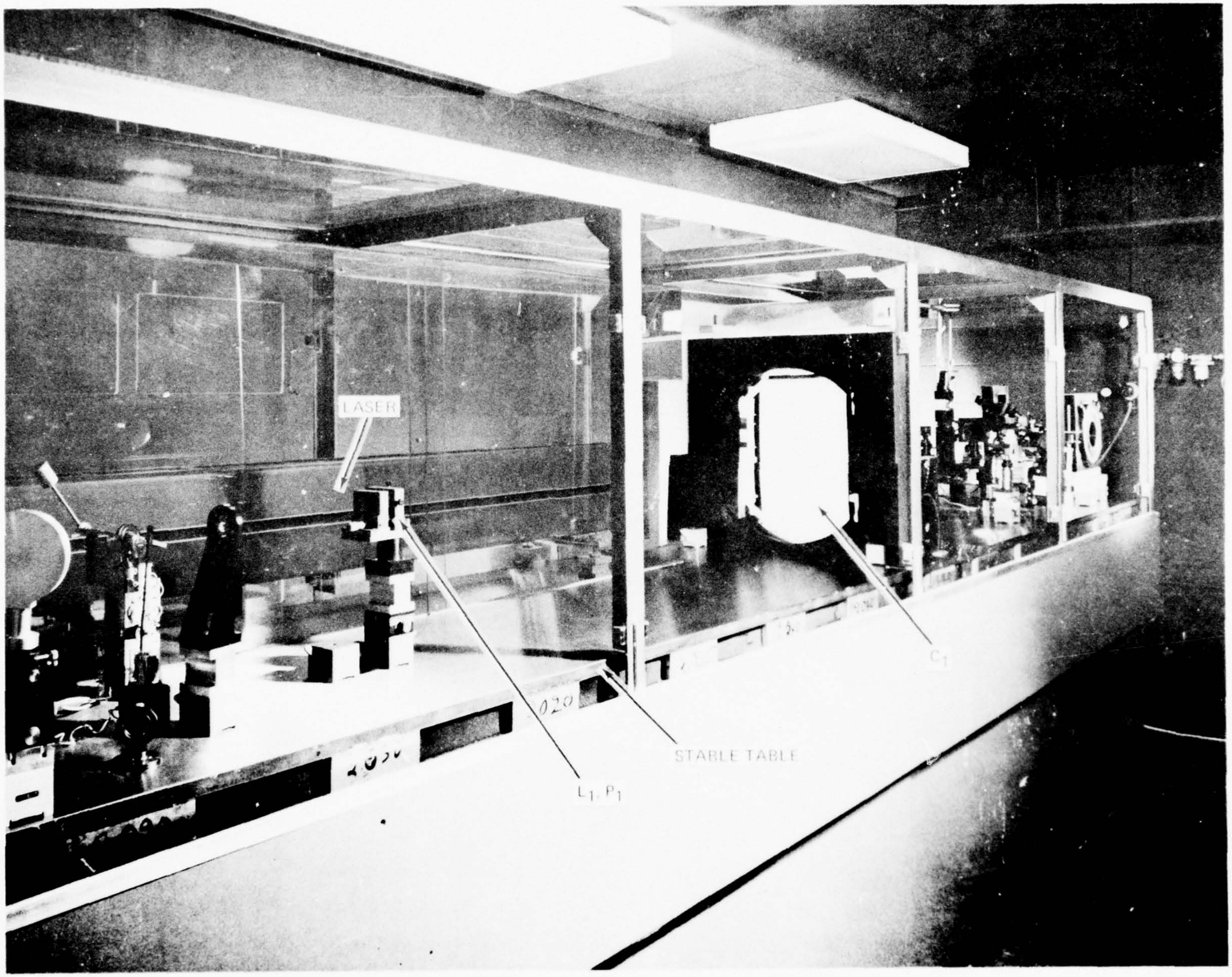


FIGURE 2-1. RECORDING HARDWARE

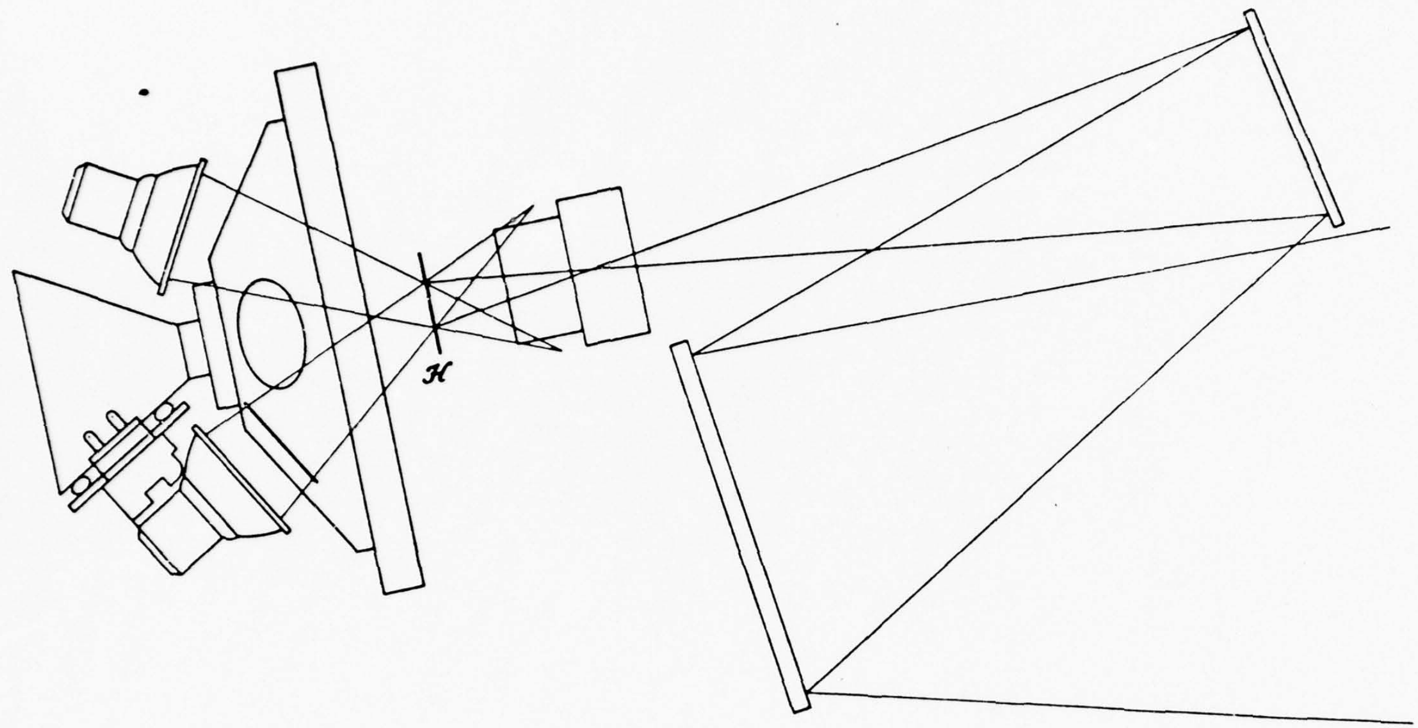


Figure 2-2 Basic Projection Optical Path

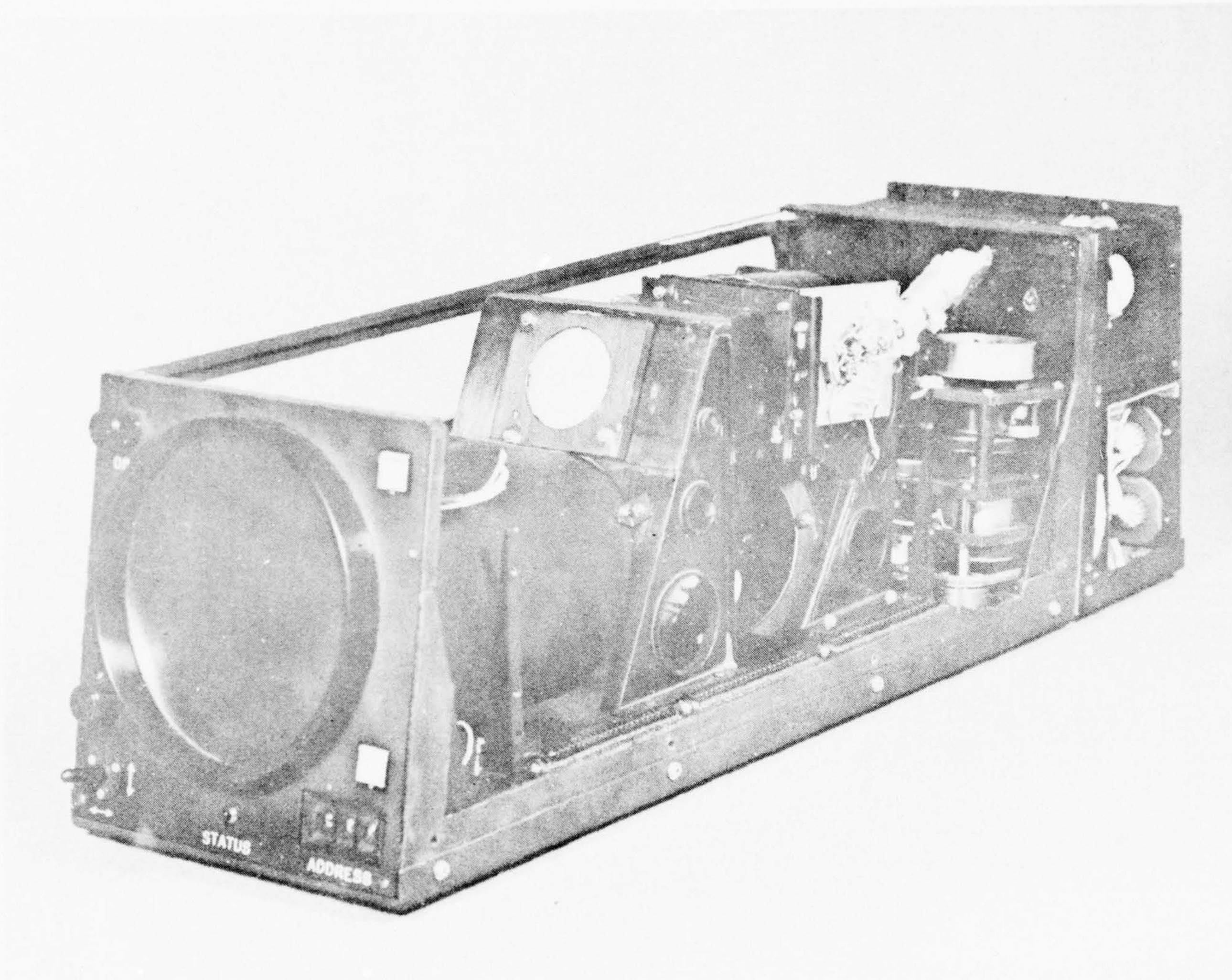


FIGURE 2-3. ORIGINAL MODEL MAP DISPLAY SYSTEM

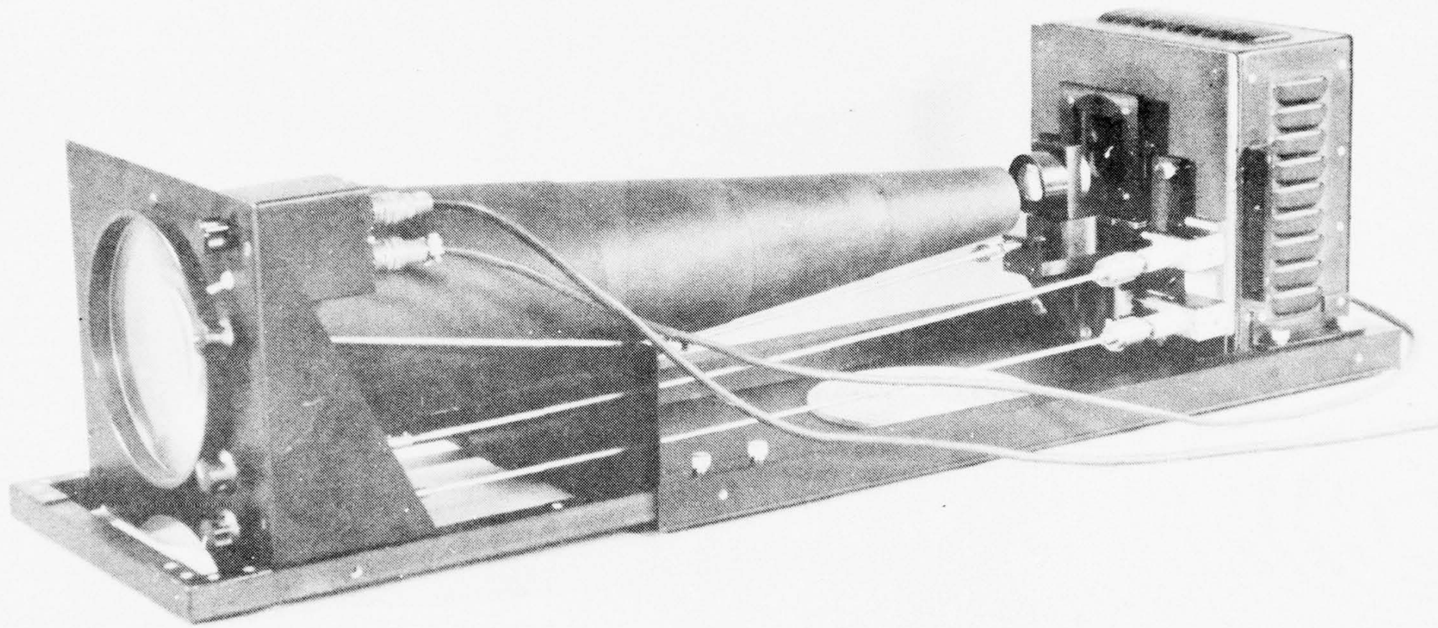


FIGURE 2-4. LABORATORY READER

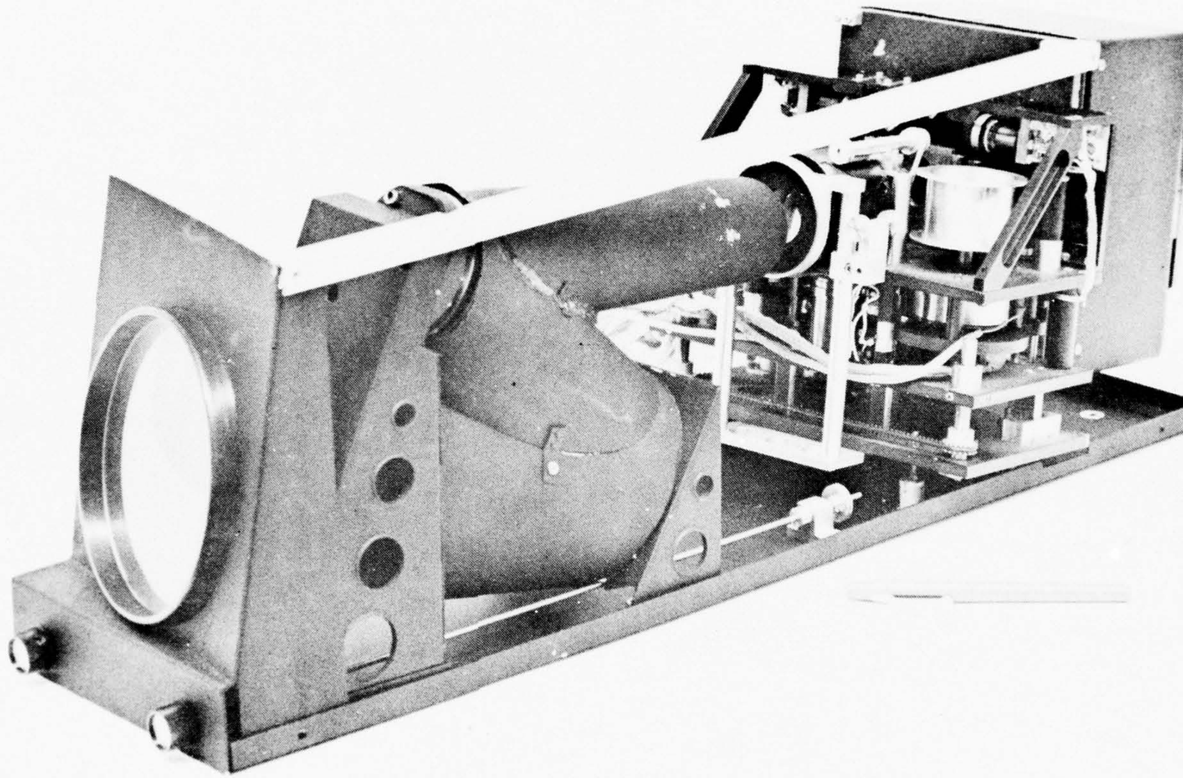
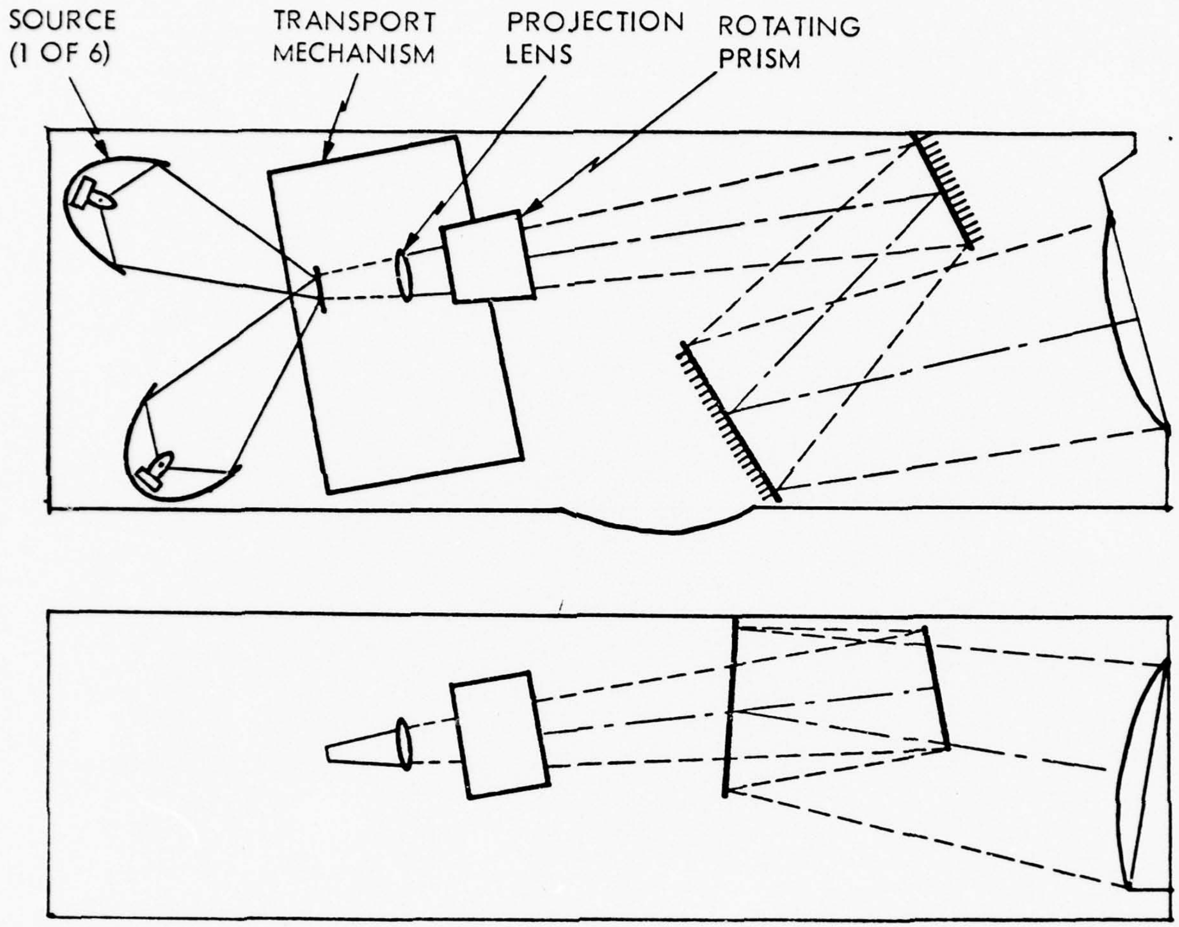
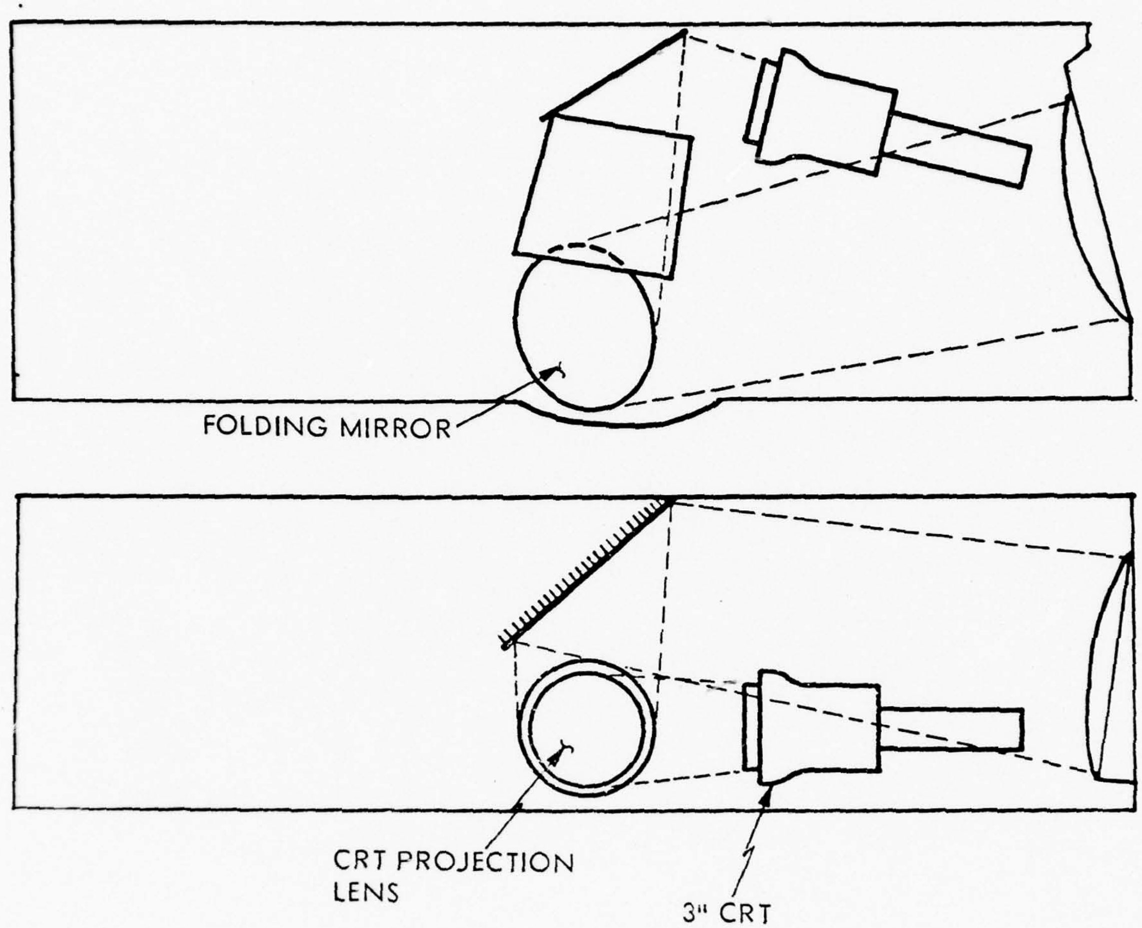


FIGURE 2-5. RECENT DISPLAY MODEL IMPLEMENTATION



a) Holographic Projection System

Figure 2-6(a) Optical Layout



b) CRT Projection System

Figure 2-6(b) Optical Layout

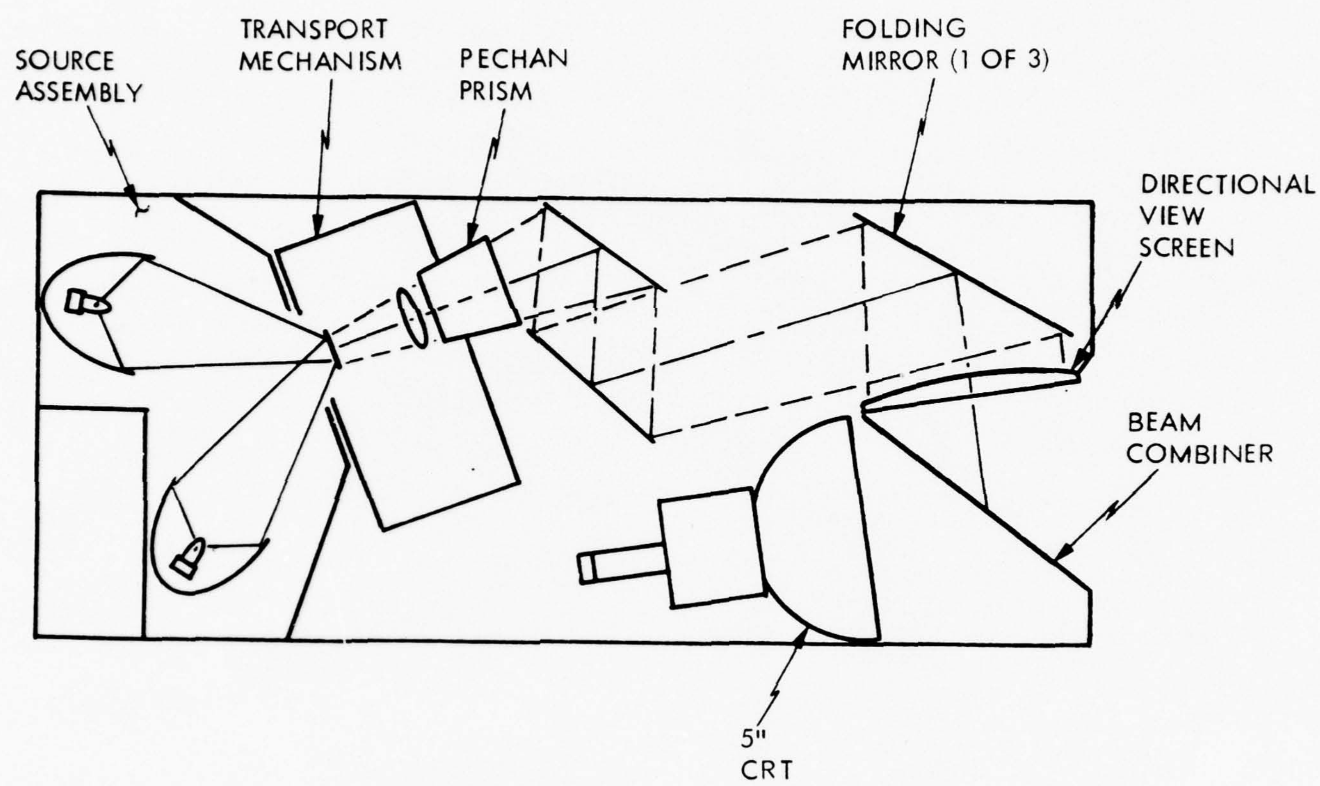


Figure 2-7 Direct View System

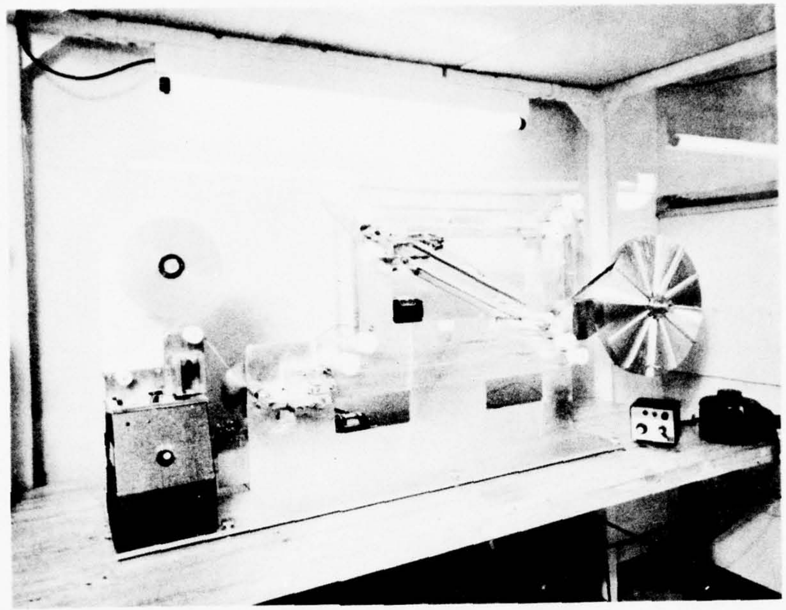


FIGURE 2-8. COATING FACILITY

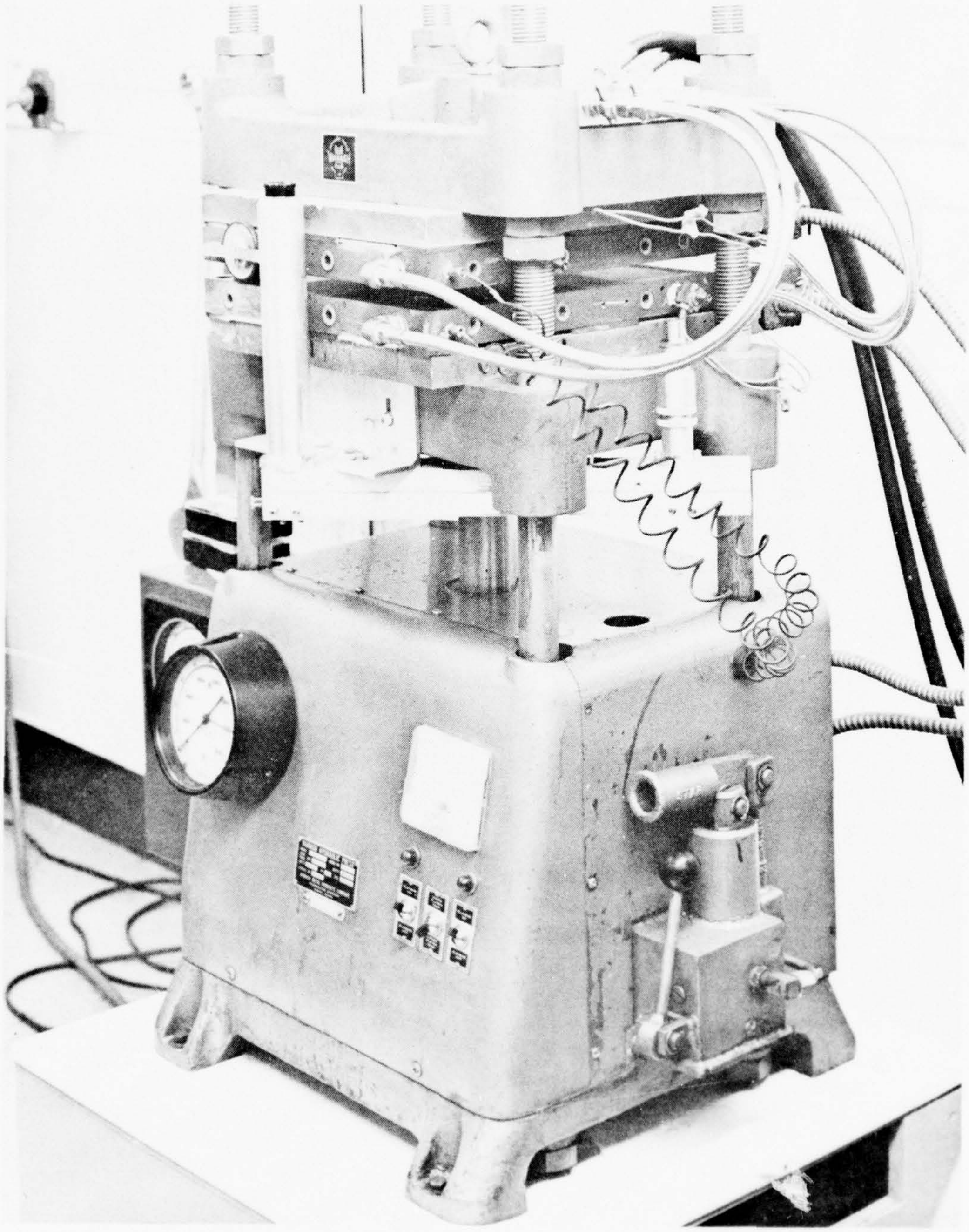


FIGURE 2-9. SINGLE SIDED PRESSING HARDWARE

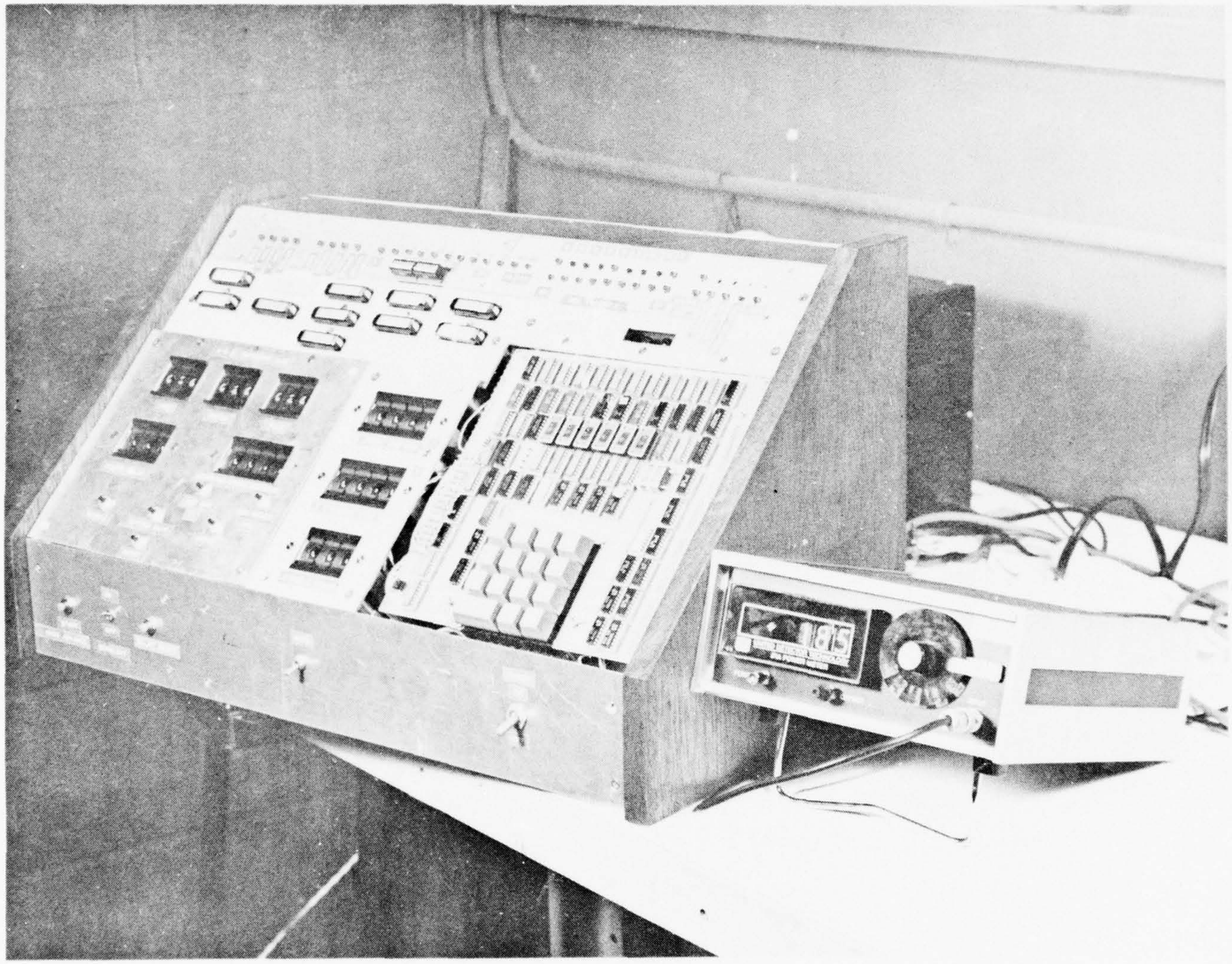


FIGURE 3-1. CONTROL SERIALIZER CONTROL PANEL

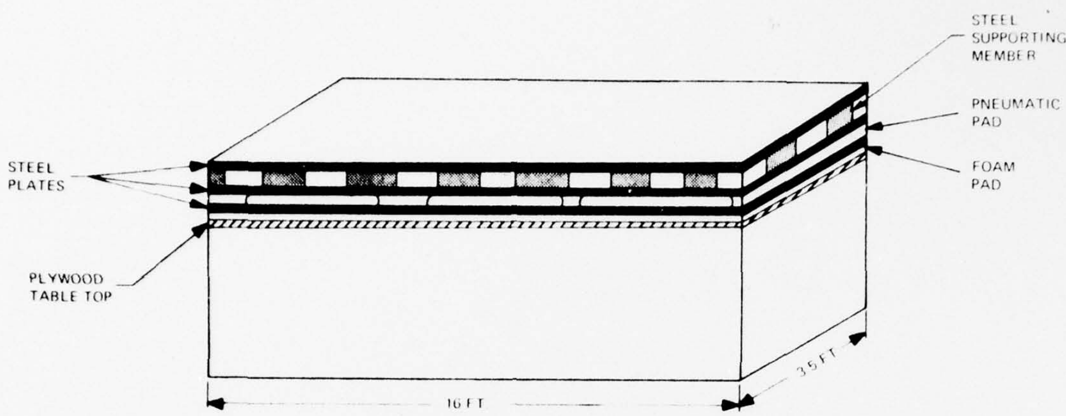


Figure 3-2 Table Structure

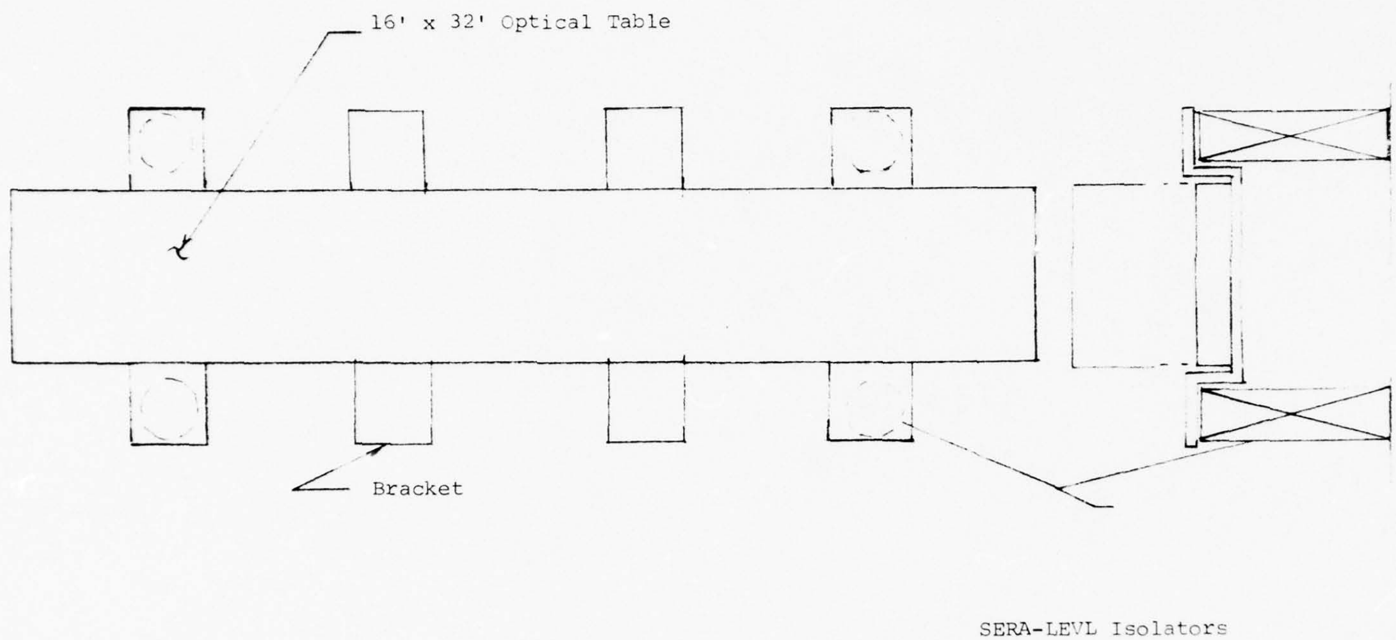


Figure 3-3   Isolation System Arrangement

SERA-LEVL
VERTICAL TRANSMISSIBILITY

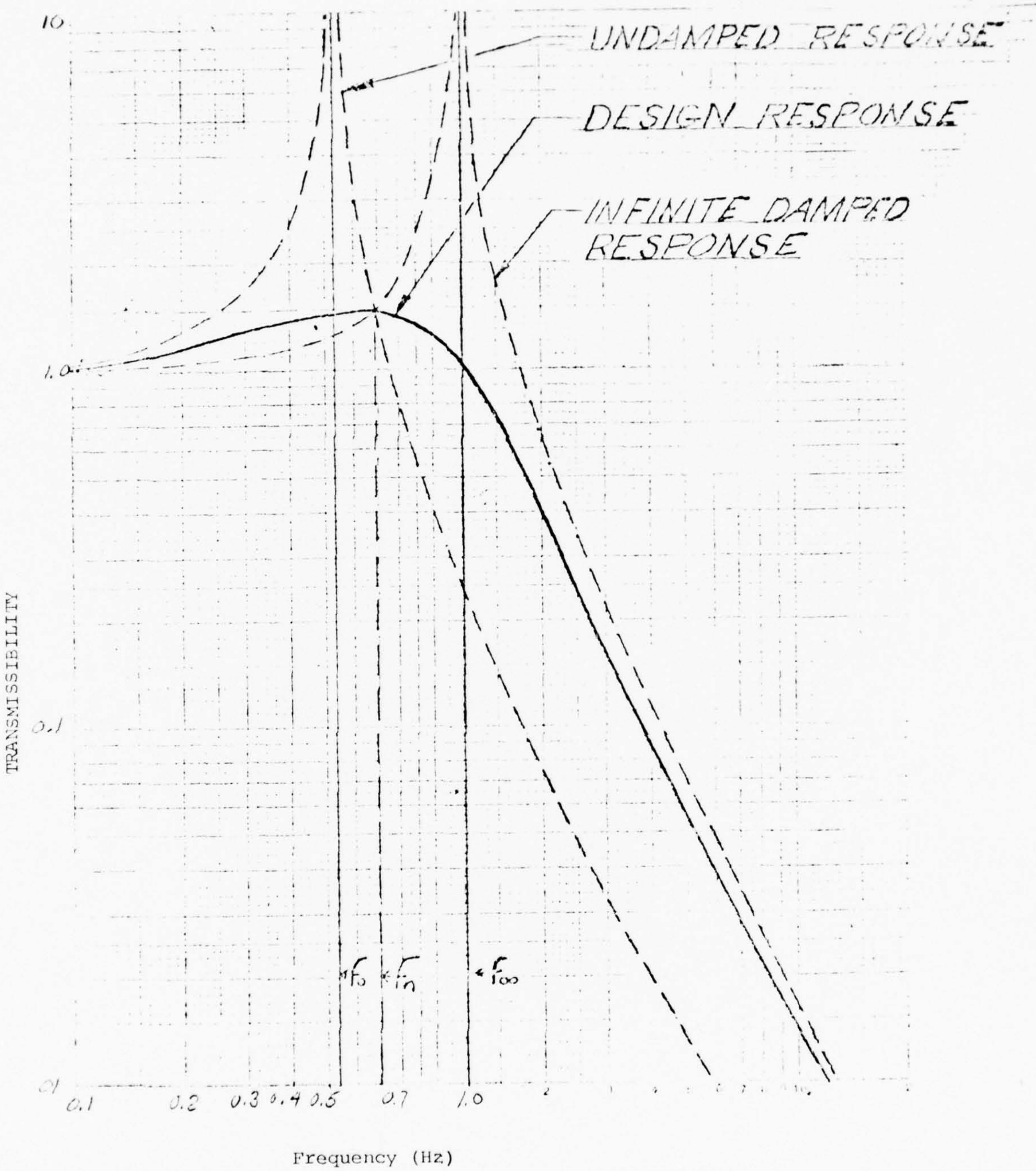


Figure 3-4 System Performance Characteristics

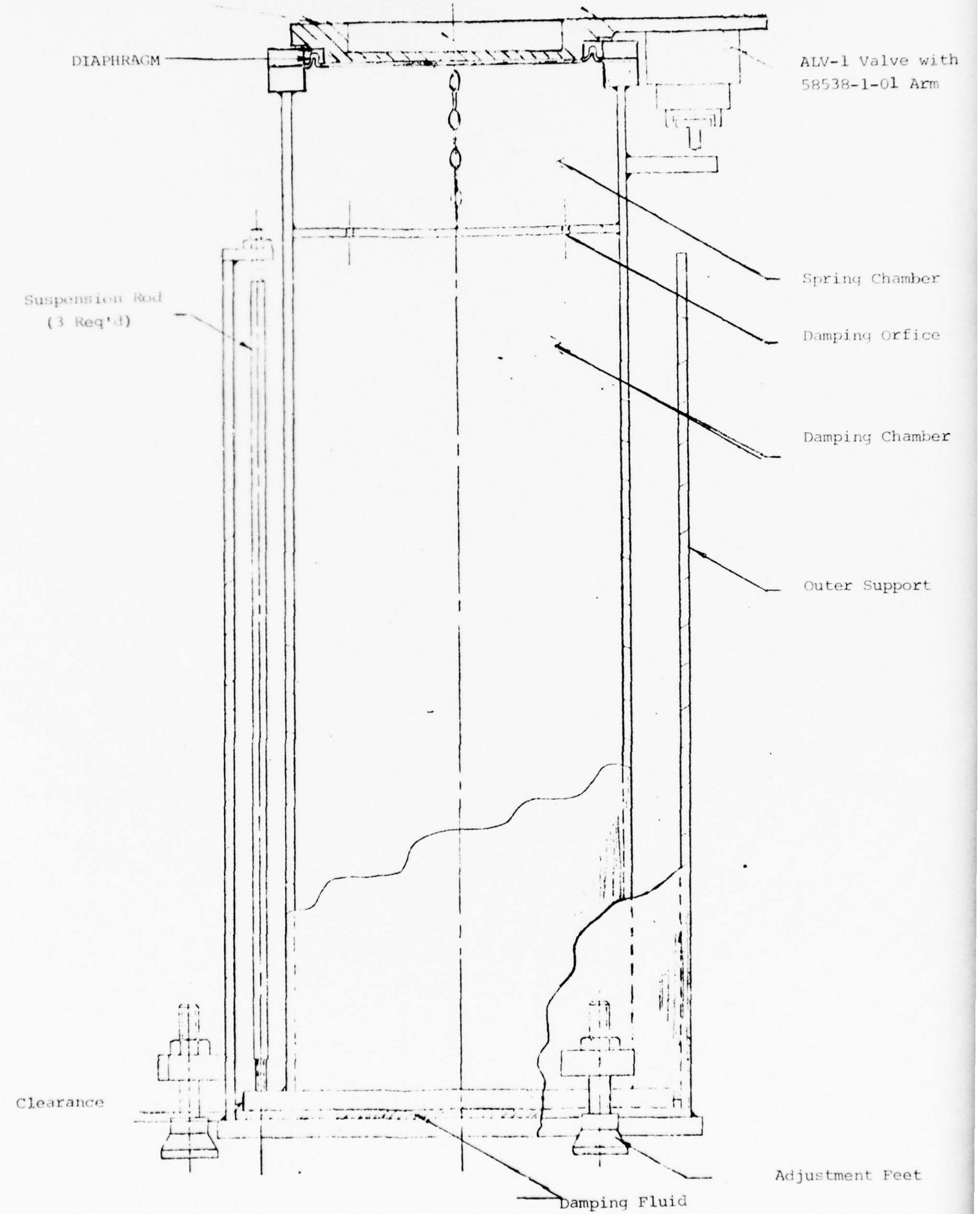


Figure 3-5 Isolator Construction

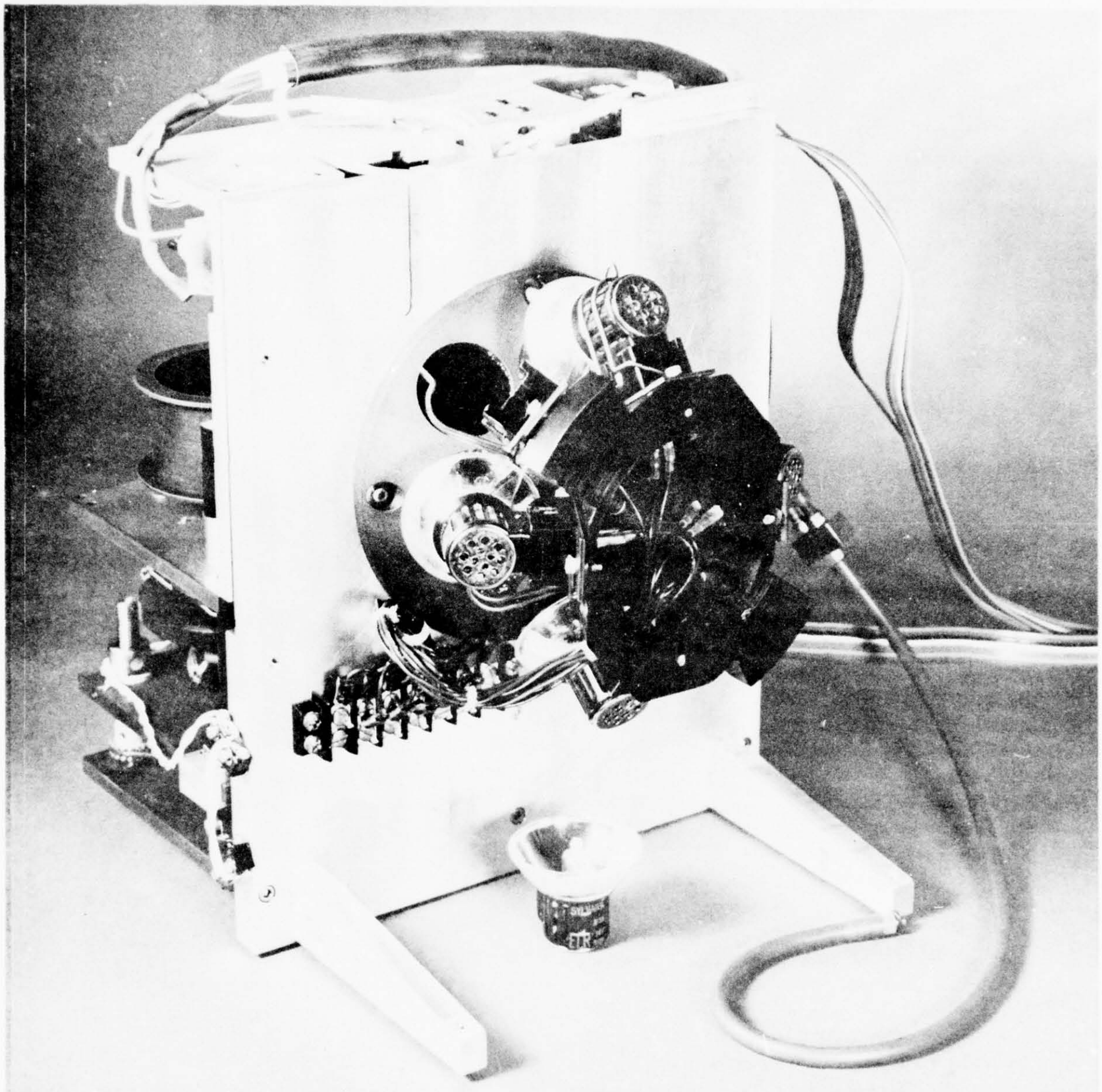


FIGURE 3-6. DEMONSTRATION MODEL SOURCE ASSEMBLY

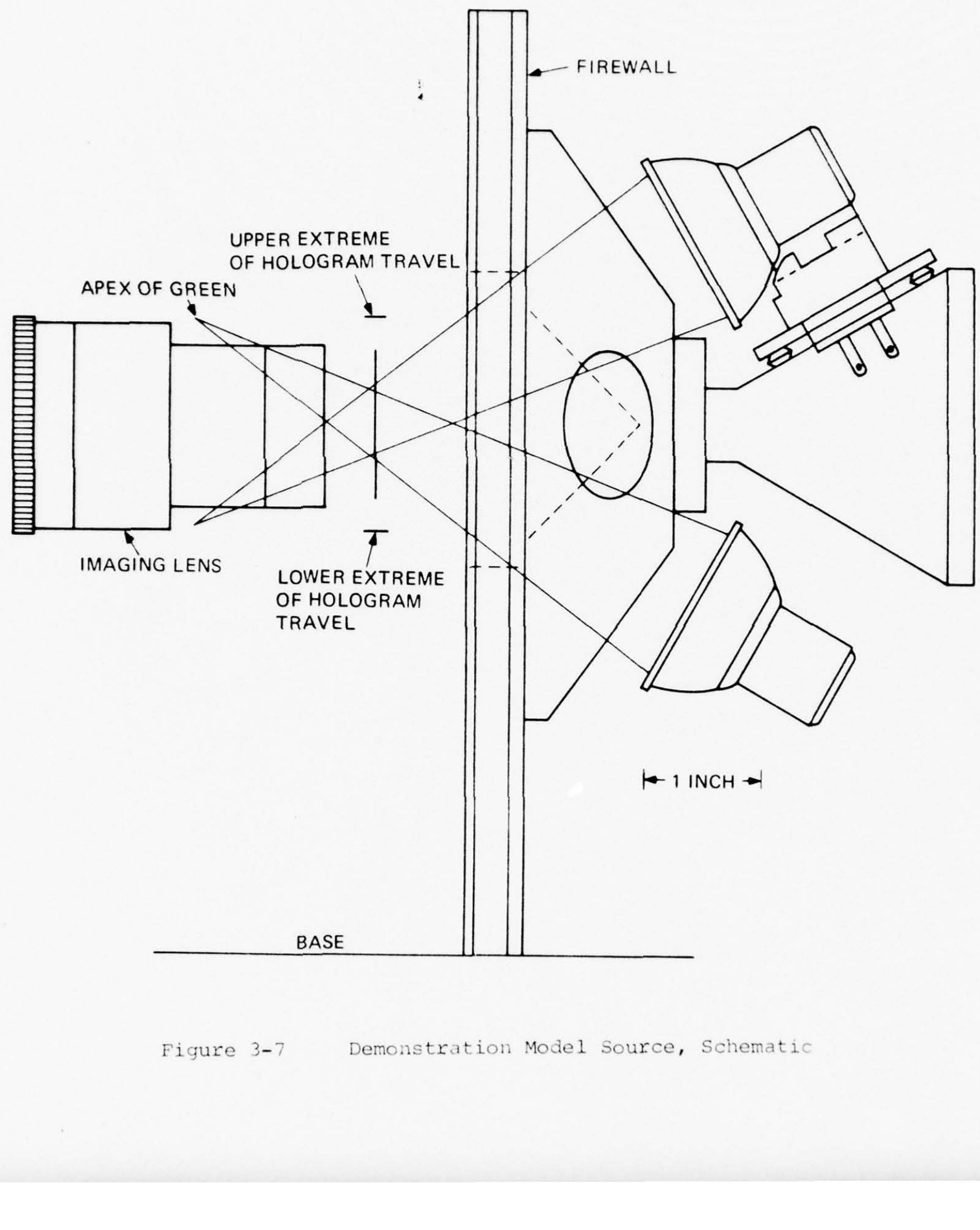


Figure 3-7 Demonstration Model Source, Schematic

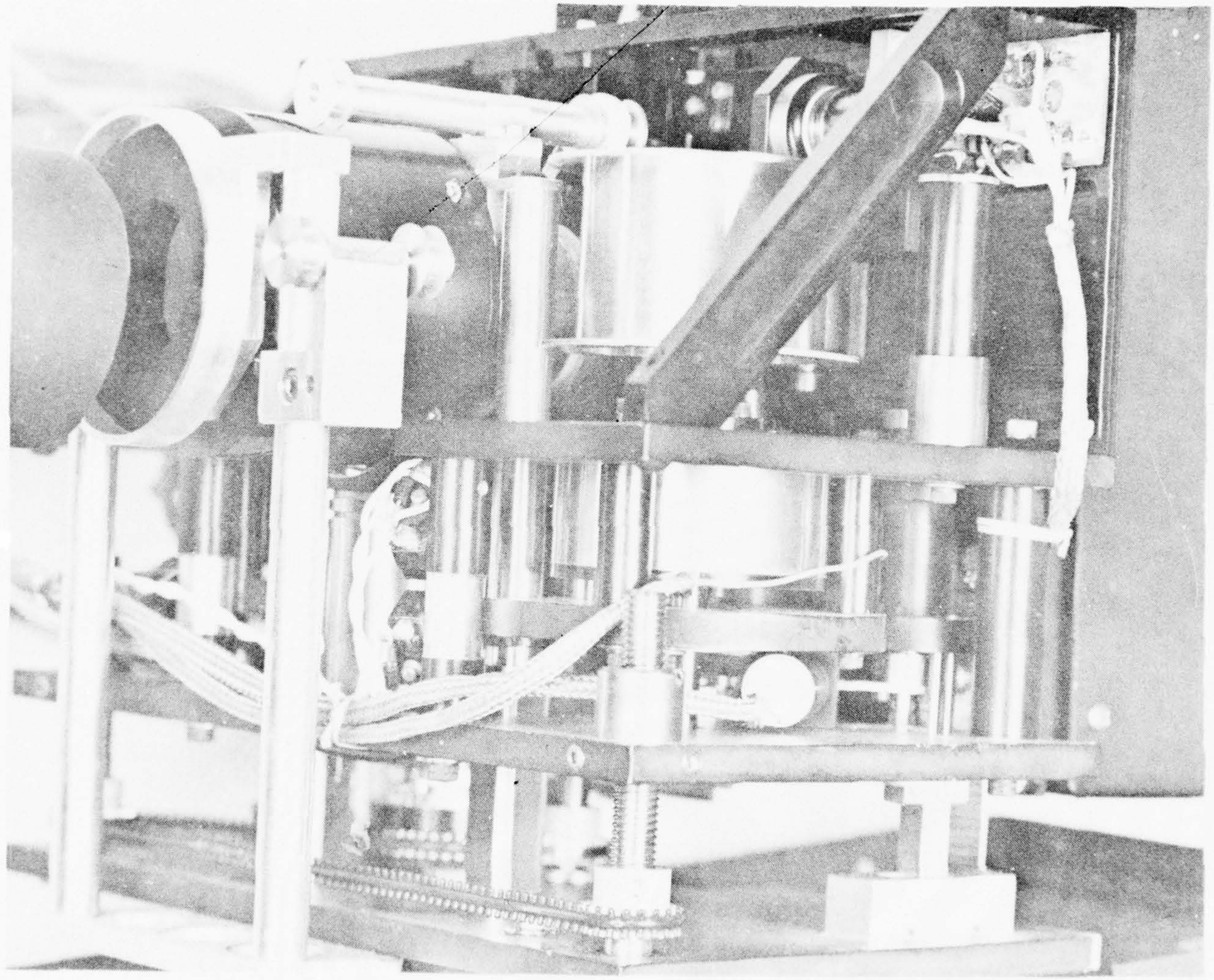
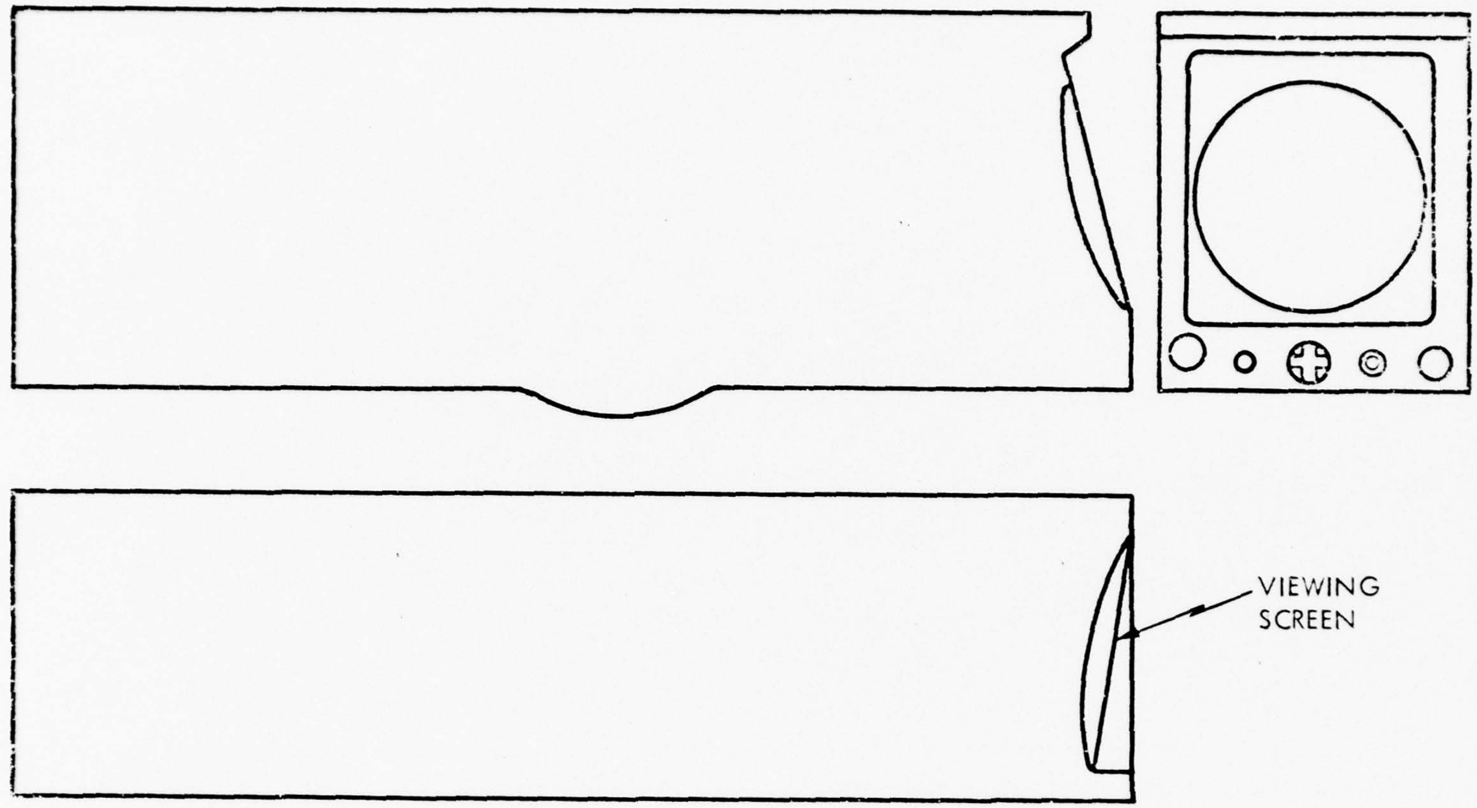


FIG. 3-8. MODIFIED TRANSPORT MECHANISM



8"(H)x6-3/4"(W)x25"(L)

5" Diameter Viewing Screen

Figure 3-9 Demonstration Hardware - Outline Dimensions

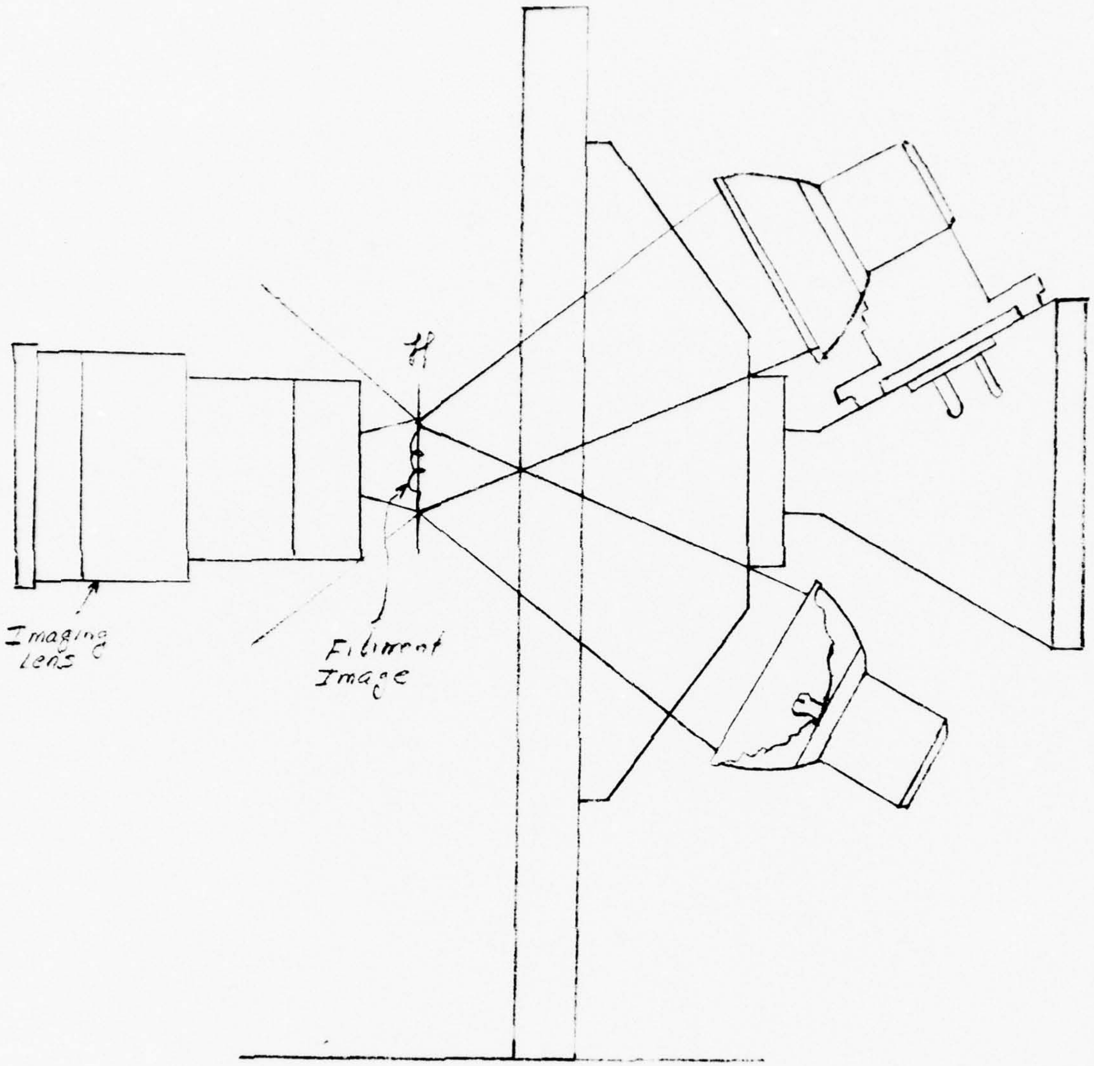


Figure 3-10 Source Configuration - Practical

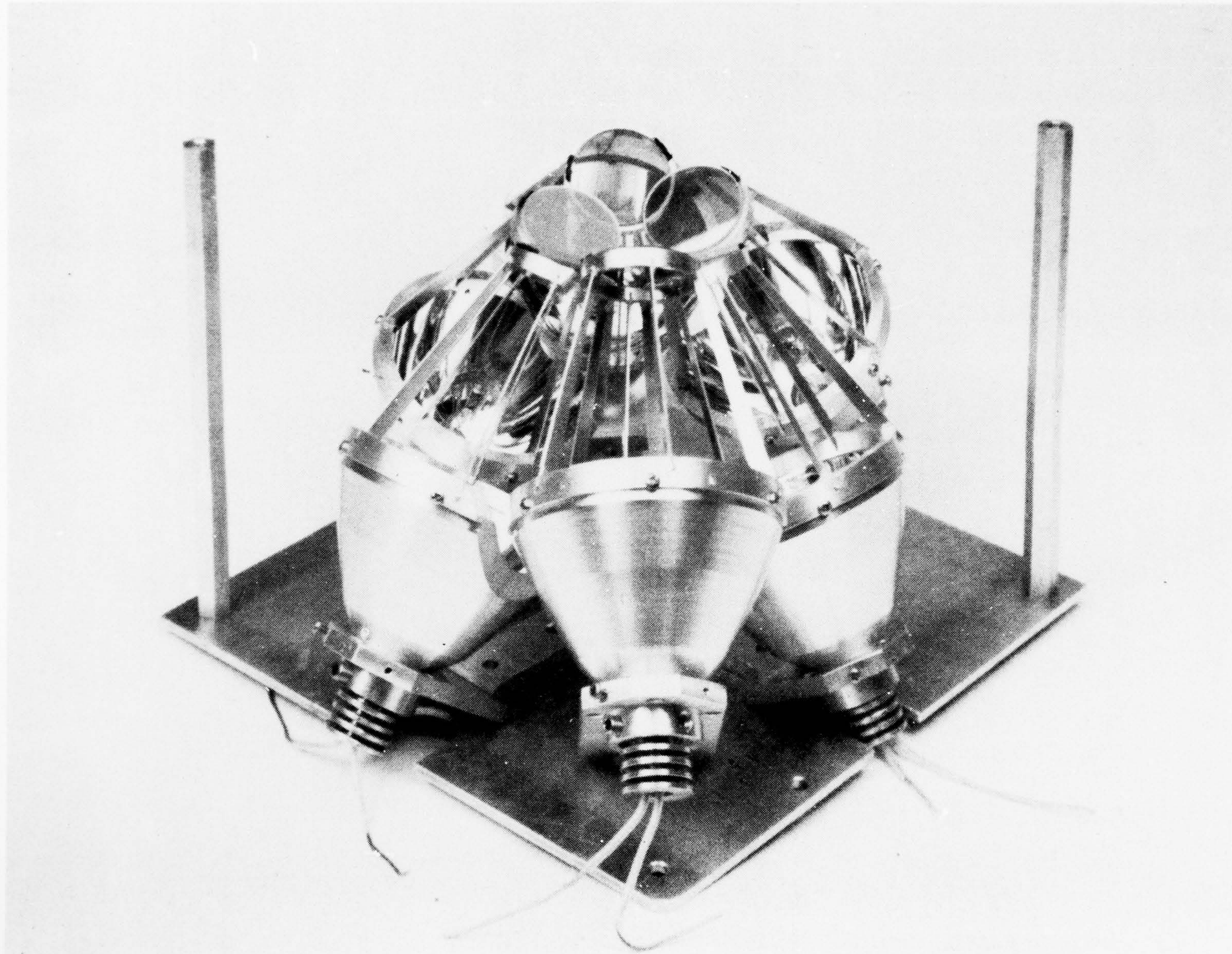
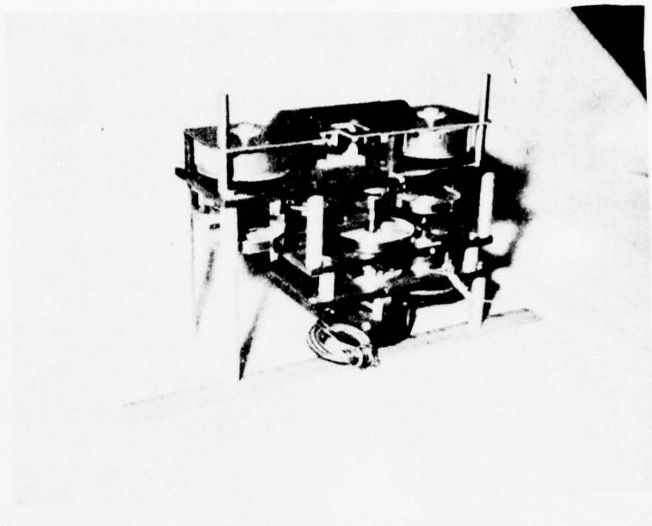
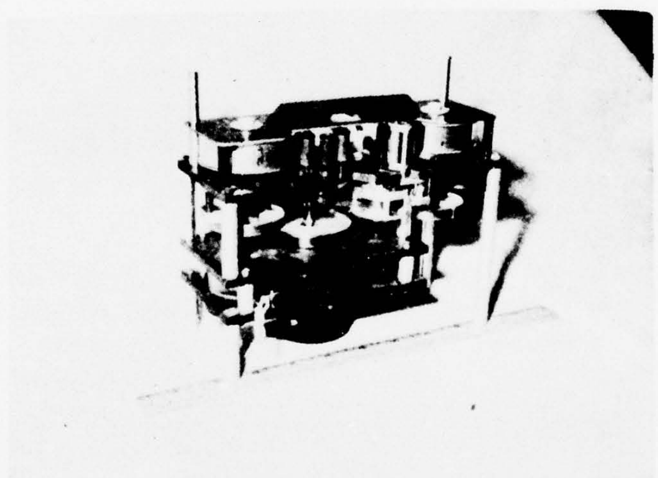


FIGURE 3-11. HIGH BRIGHTNESS SOURCE ASSEMBLY



a) Front View



b) Rear View

FIGURE 3-12. TRANSPORT MECHAMISM - ORIGINAL VERSION

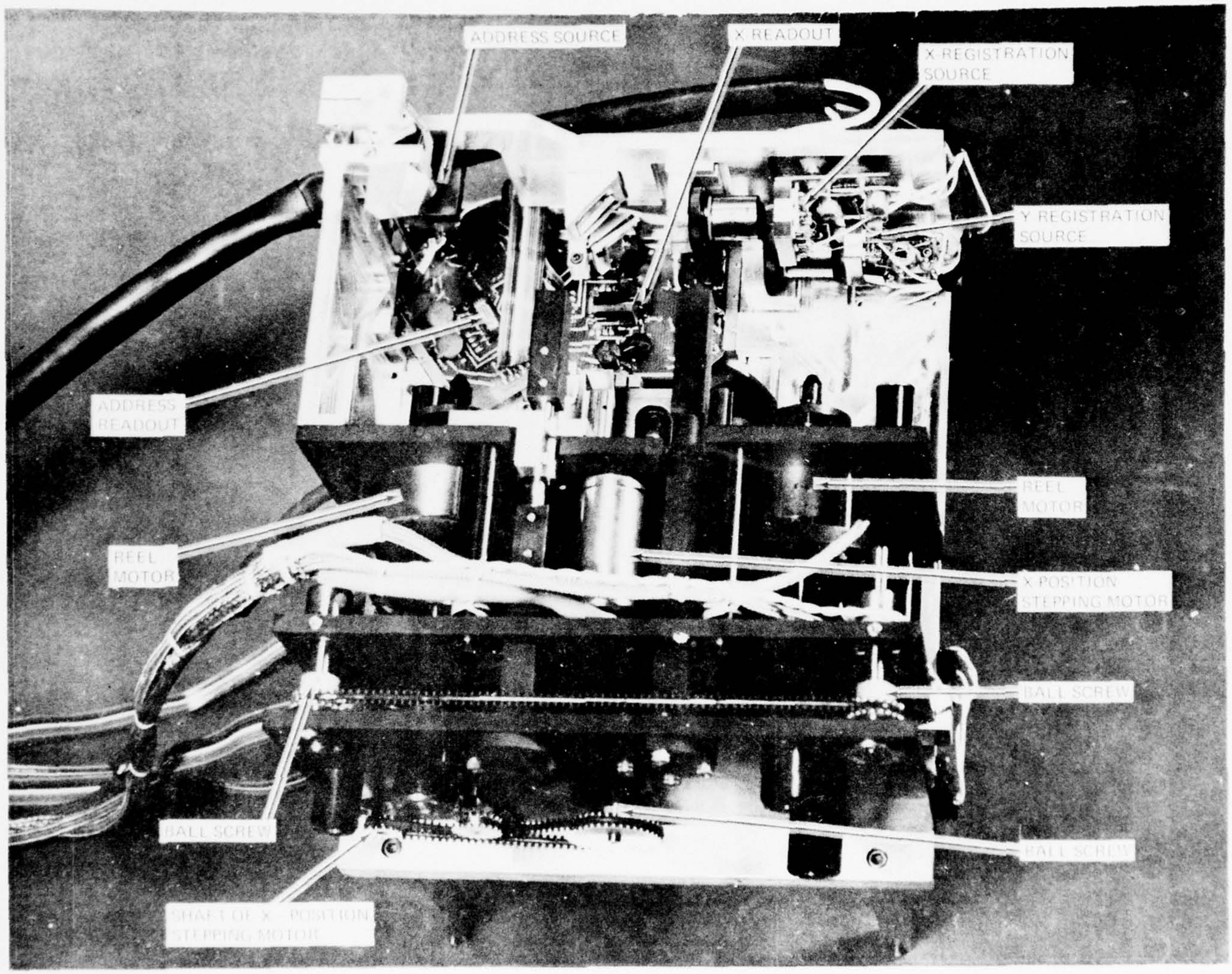


FIG. 3-13. TRANSPORT MECHANISM - ORIGINAL 32mm VERSION

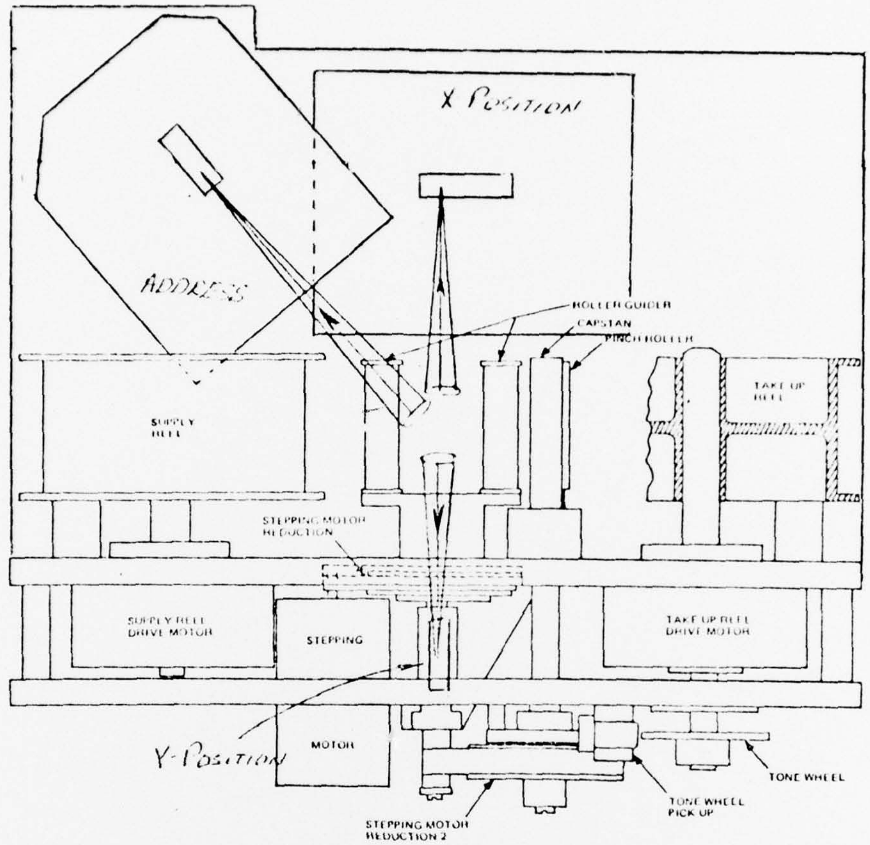
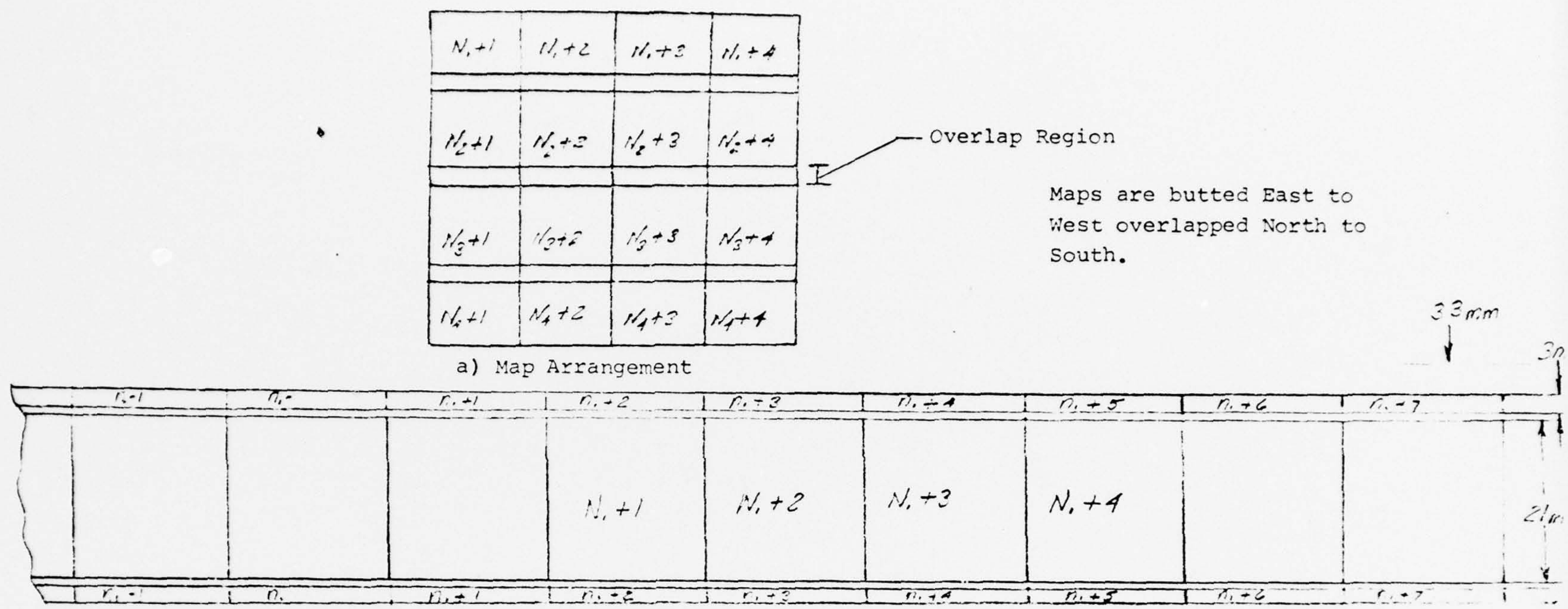


Figure 3-14 Transport Mechanism Schematic



a) Map Arrangement

b) TAPE STRIP ARRANGEMENT

1) Multicolor Map Storage Area

2) X-Registration Hologram

3) Y-Registration Hologram

The n-1 to n+7 pattern consisting of 4 active storage frames N+1 thru N+3 and 9 address frames will be repeated along the length of the type strip with the data from 16 map frames distributed over the 4 groups.

Figure 3-15 Storage Tape Configuration

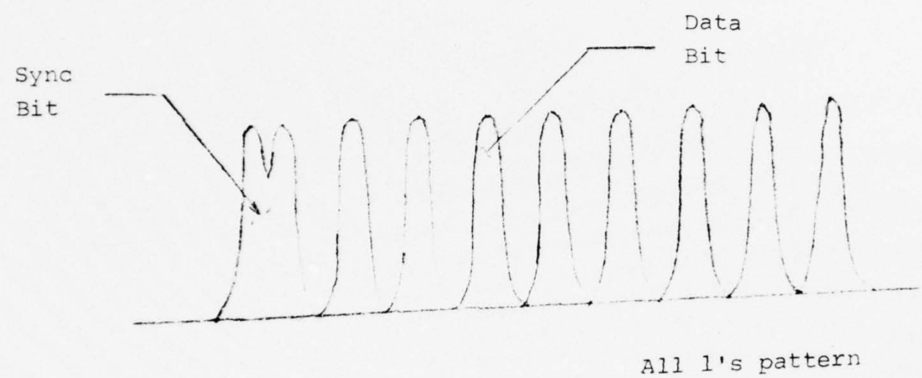


Figure 3-16 Address Bit Pattern

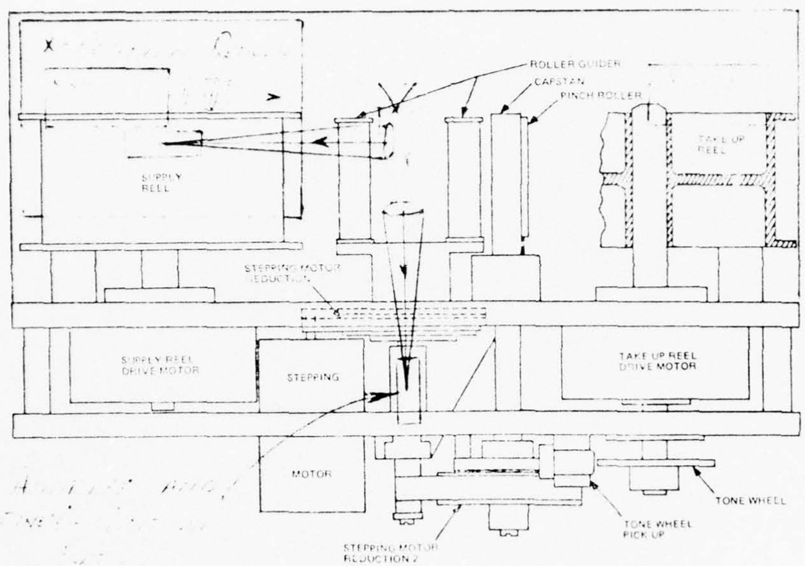
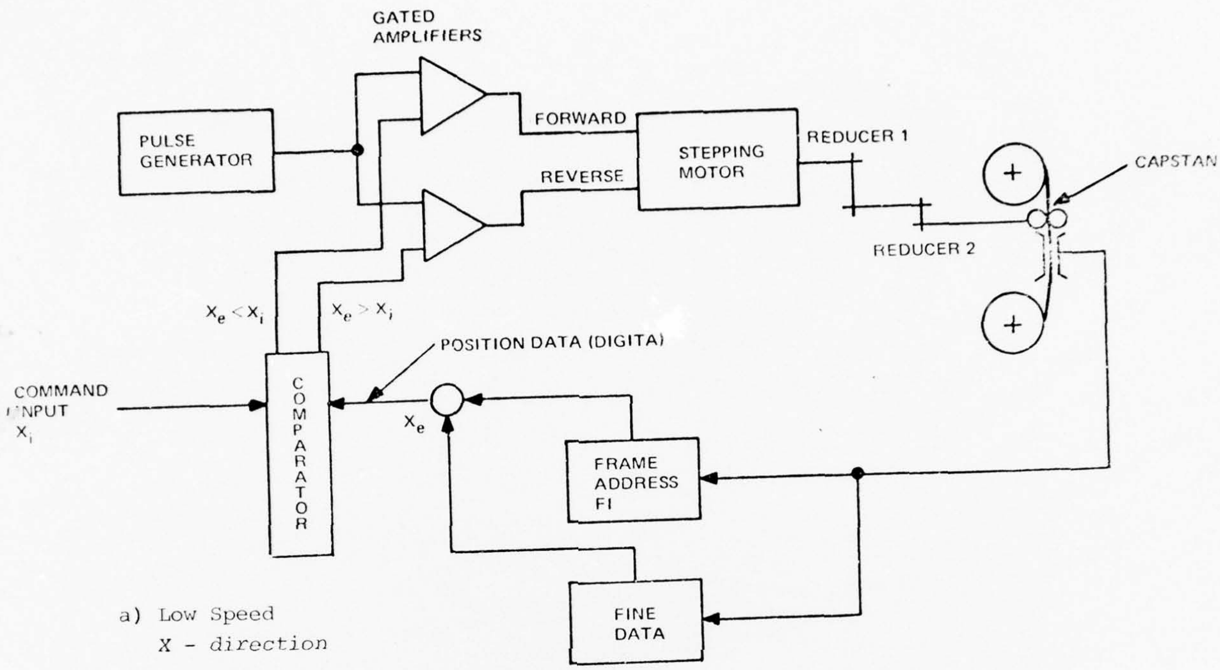
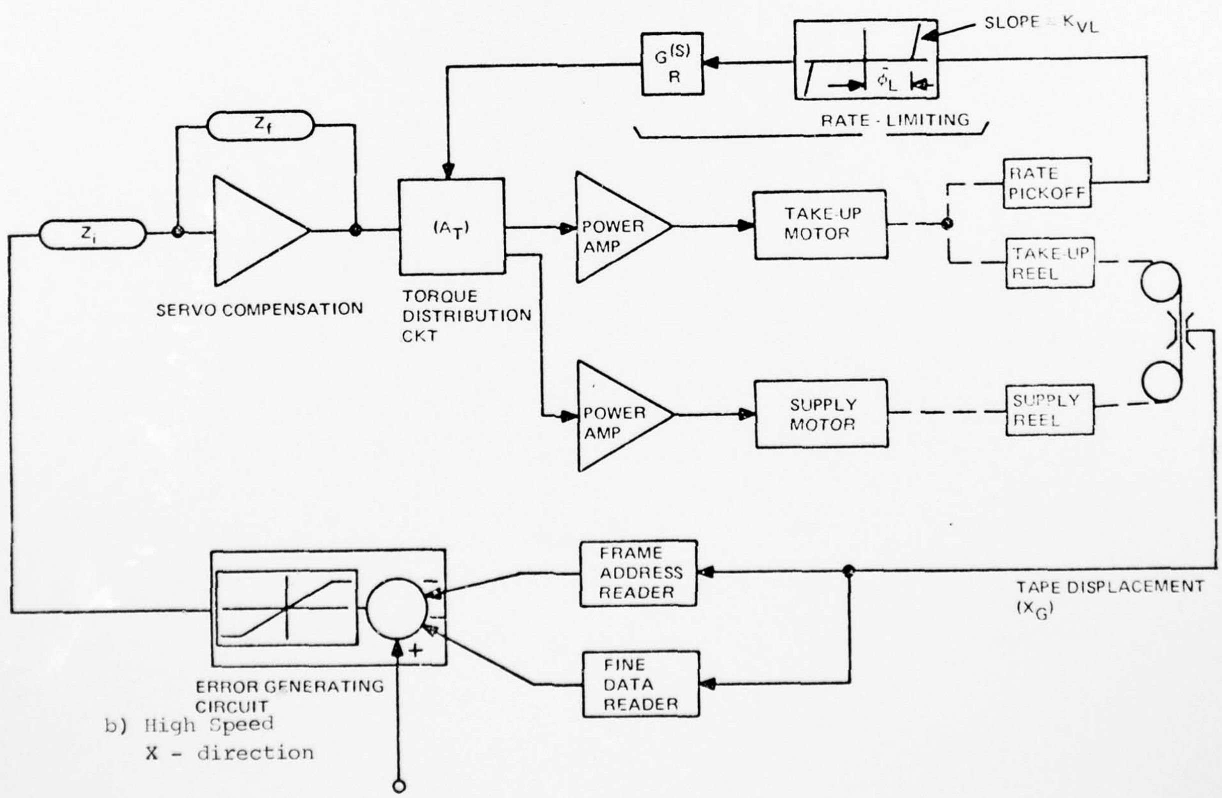


Figure 3-17 Modified Transport Mechanism - Schematic



a) Low Speed
X - direction



b) High Speed
X - direction

Figure 3-18 Transport Subsystem Block Diagram

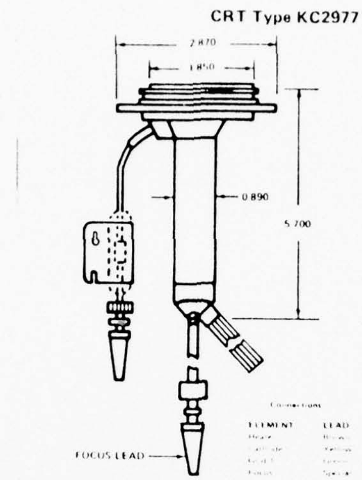
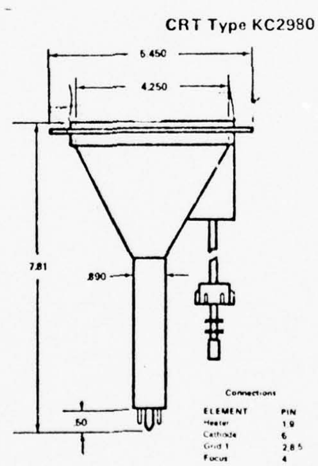


Figure 3-19 Projected CRT - Outline Drawing



Note: The CK2980 will be extended in length to provide an active 5" diameter display.

Figure 3-20 Direct View CRT System - Outline Drawing

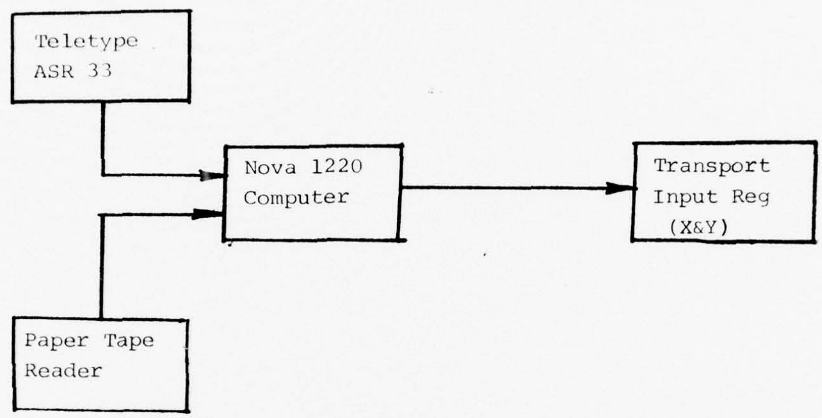
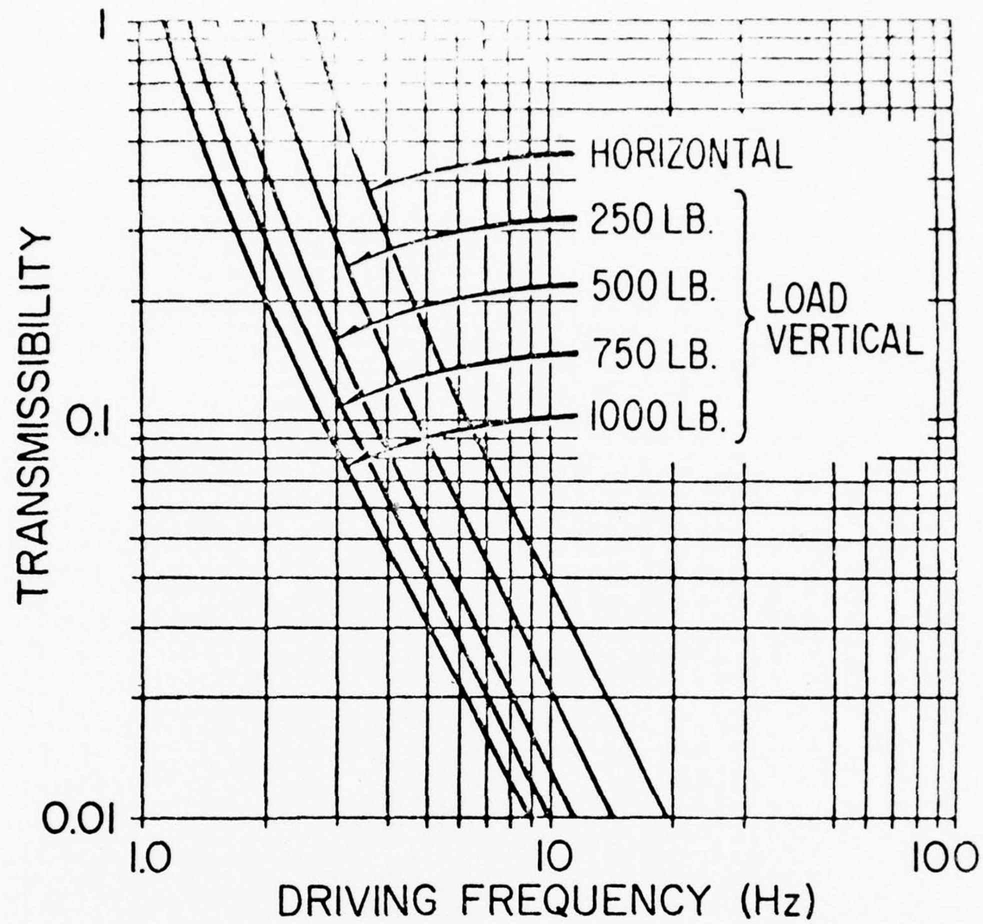
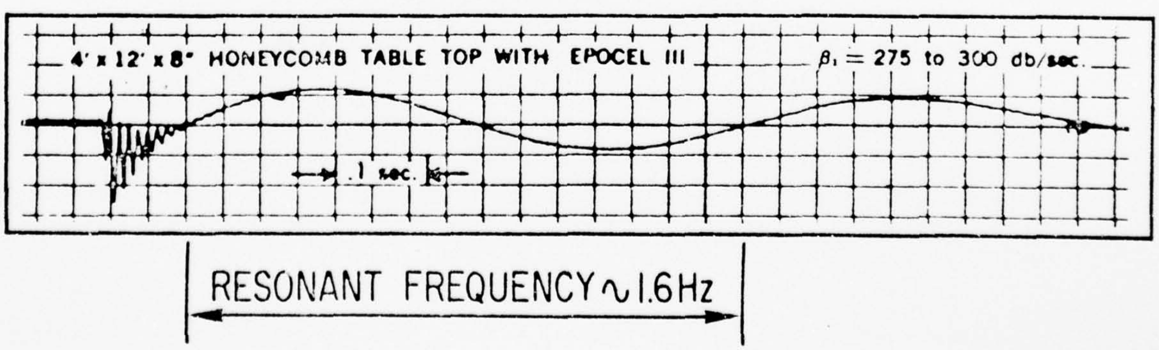


Figure A2-1 Control System Configuration





RESPONSE OF TABLE TO IMPULSE EXCITATION

Figure A4-1 Stable Table Characteristics

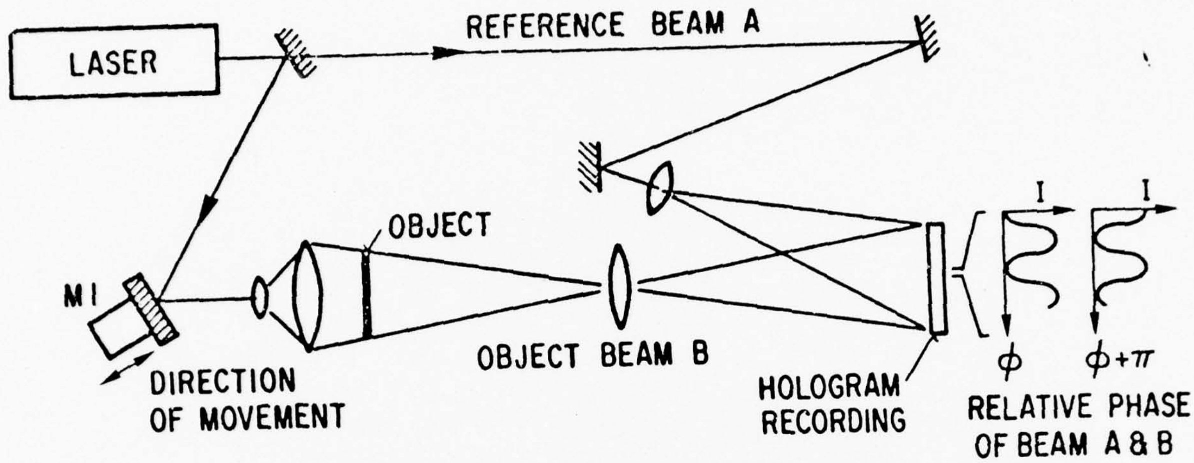
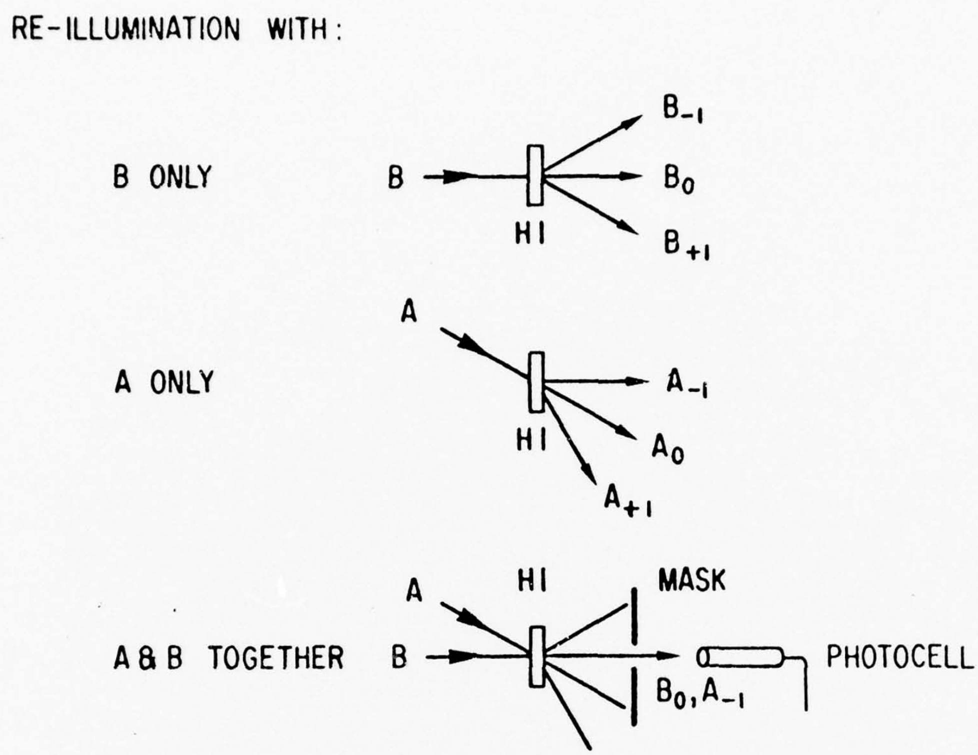
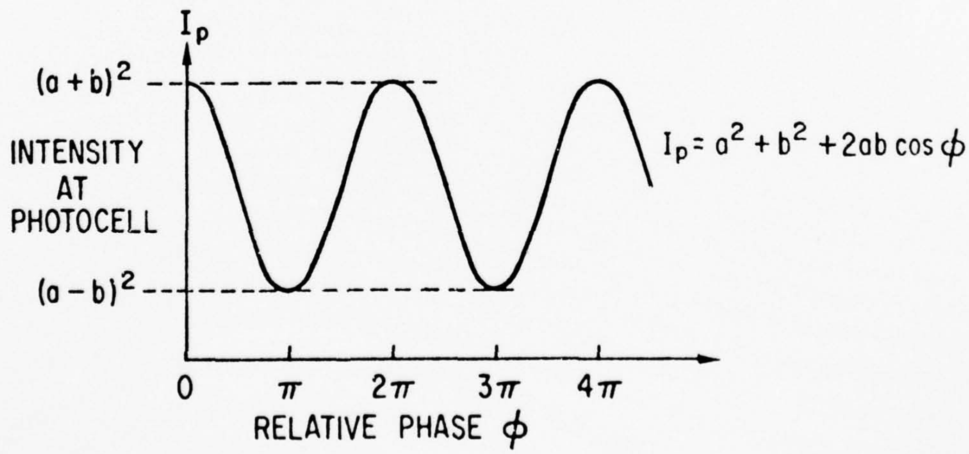


Figure A4-2 Recording System



(b)



(a)

Figure A4-3 Error Signal Extraction and Characteristics

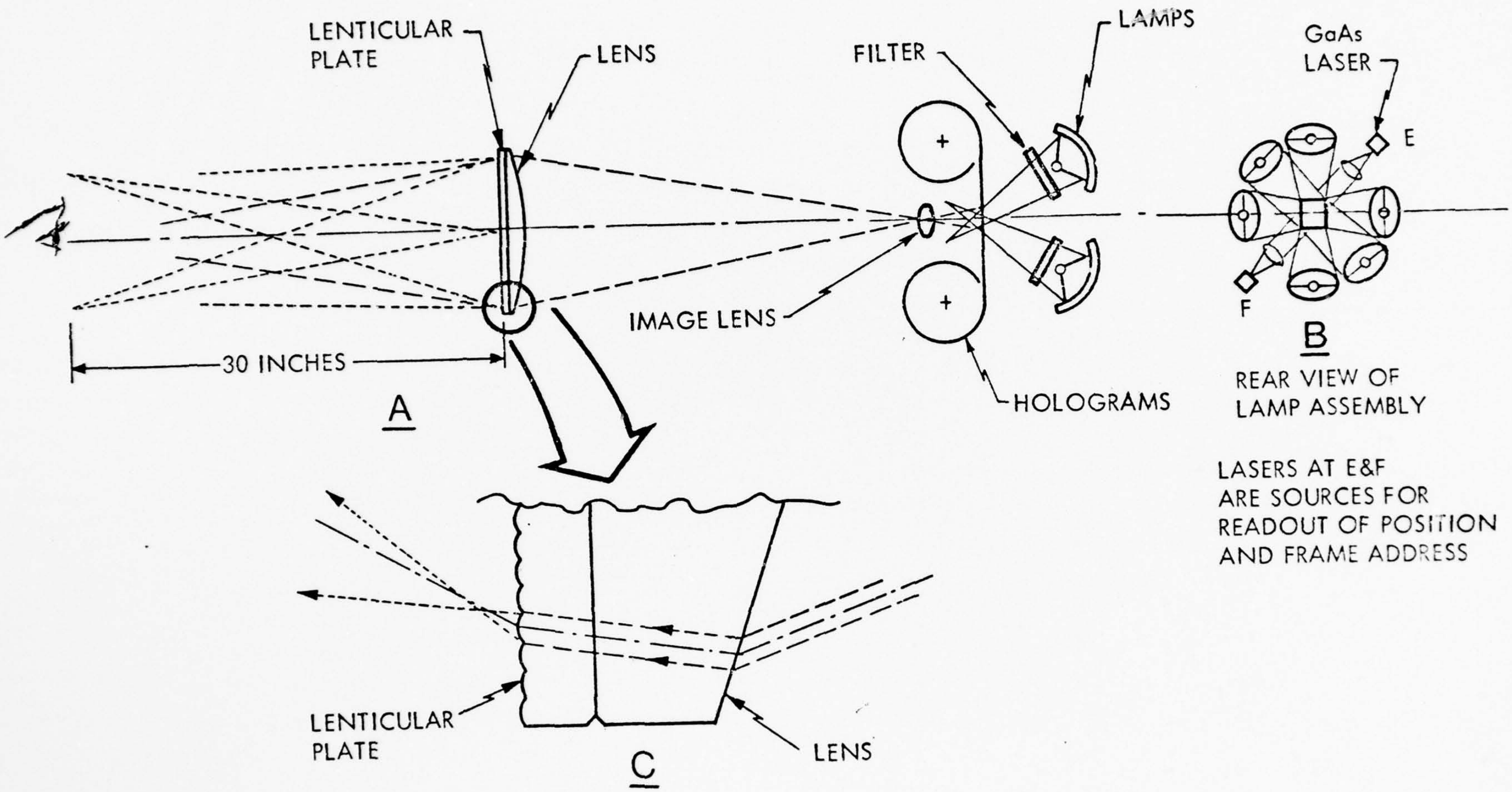


Figure A5-1 Directional Viewing Screen Geometry

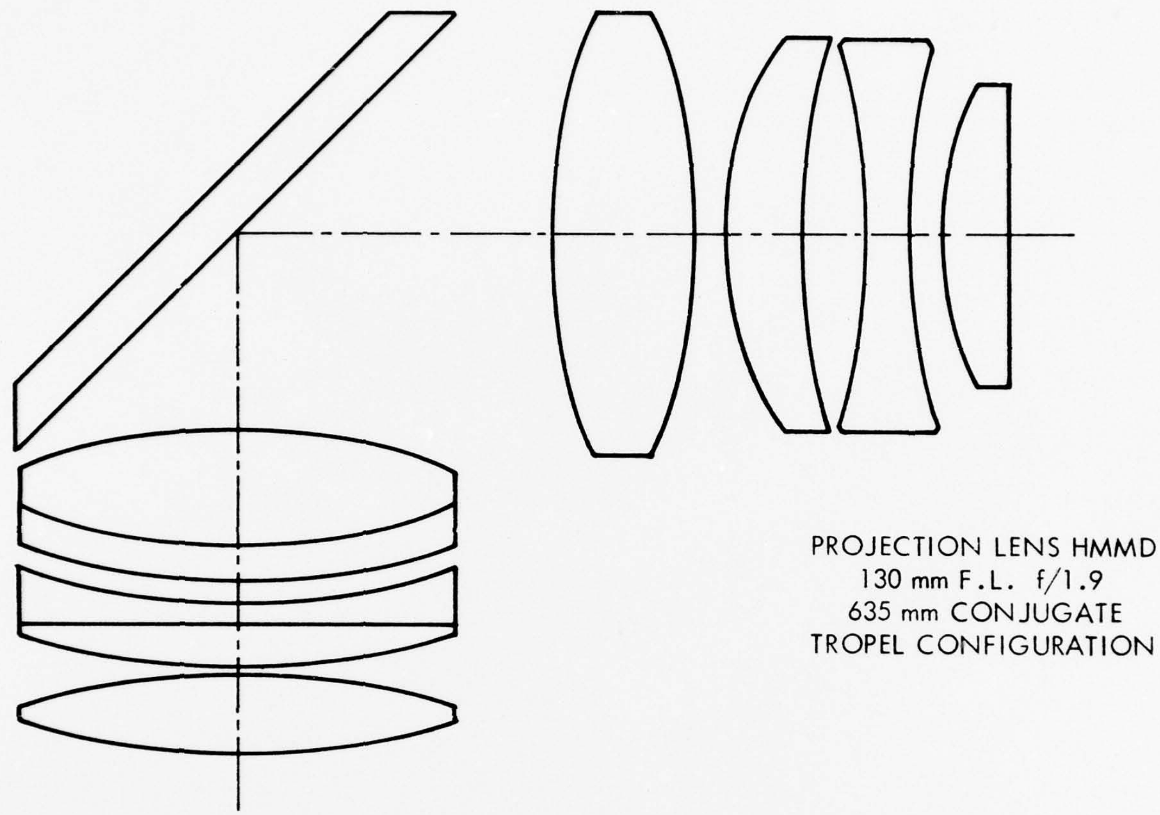


FIG. A5-2. TROPEL LENS CONFIGURATION